CHAPTER 3

THE CONCEPT THROUGH CONSTRUCTION PROCESS FOR STREET STORAGE SYSTEMS

Status of Urban Stormwater Management

As briefly noted in Chapter 1, the street storage system mitigates surcharging of CSSs by managing stormwater—by reducing peak rates of stormwater before it enters the combined sewer system. Accordingly, a brief review of the status of urban stormwater management, with emphasis on detention, that is, temporary storage of stormwater, is appropriate. The following review is taken from Walesh (1989, pp. 20-31) and other sources as indicated.

Two Fundamentally Different Approaches: Conveyance-Oriented and Storage-Oriented

The state of the art of stormwater management has evolved to the point where there are two fundamentally different approaches to controlling the quantity, and to some extent the quality, of stormwater runoff. Using a “before and after” format. Figure 3-1 illustrates selected characteristics of the two available approaches.

Conveyance-Oriented Approach

The first to the two approaches is the more traditional conveyance-oriented stormwater system. Systems designed in accordance with this approach provide for the collection of stormwater runoff, followed by the immediate and rapid conveyance of the stormwater from the collection area to the discharge point to minimize damage and disruption within the collection area. Principal components of conveyance-oriented stormwater systems are culverts, storm sewers, and channels supplemented with inlets and catch basins.

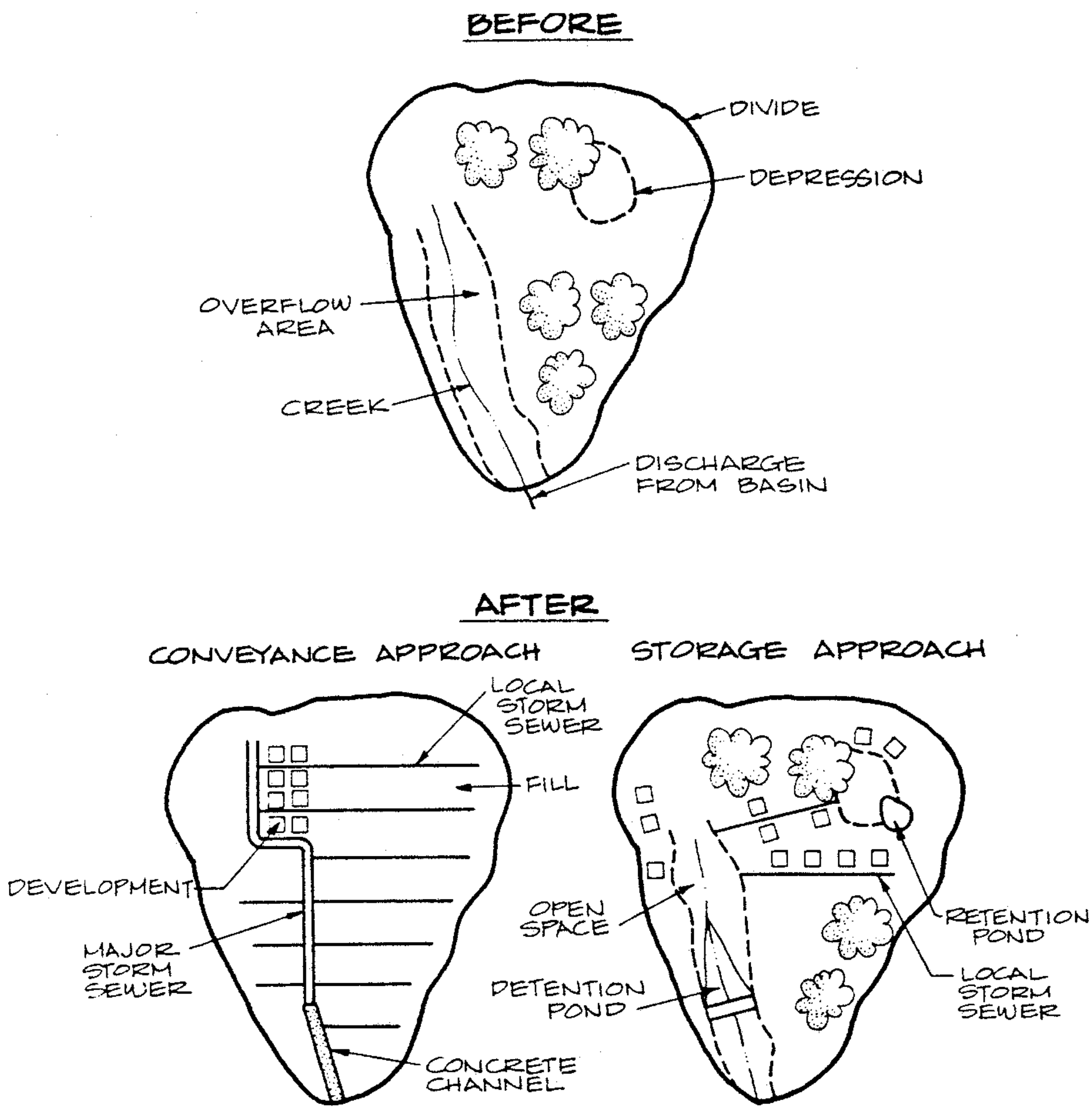


Figure 3-1. Conveyance and storage approaches to stormwater management (Source: Walesh, 1989, p. 26).

A potentially effective, newer approach to stormwater control is the storage-oriented system. Its function is to provide for the temporary storage of stormwater runoff at or near the point of origin, with subsequent slow release to downstream storm sewers or channels. This approach minimizes damage and disruption both within and downstream of the site. One or more storage facilities are the principal elements in a storage-oriented system. These principal elements are often supplemented with conveyance facilities, such as culverts, storm sewers, inlets, and catch basins, which transport stormwater to storage facilities and gradually convey flow from those facilities.

Comparison of Features

A principal advantage of the traditional conveyance-oriented approach is applicability to both existing and newly developing urban areas, contrasted with the storage-oriented approach. Storage is more difficult to retrofit into already developed areas because of space limitations. Although retrofitting storage into developed areas is difficult, it is not impossible and it is sometimes cost effective as clearly demonstrated by the Skokie and Wilmette projects.

Other advantages of the conveyance-oriented approach are rapid removal of stormwater from the service area, minimal operation and maintenance requirements and costs, and accepted analysis and design procedures. Principal advantages of the storage-oriented approach are possible cost reductions in newly developing urban areas, prevention of downstream adverse flooding and pollution associated with stormwater runoff, and potential for multiple-purpose uses.

Neither the conveyance-oriented approach nor the storage-oriented approach is inherently better. Both approaches should be considered, at least when a project or development is at the conceptual level.

The conveyance- and storage-oriented approaches to stormwater management are not necessarily mutually exclusive within the same hydrologic-hydraulic system. Depending on the circumstances, the two approaches may be compatible and integrated use of the two approaches may lead to a more optimum stormwater management system. One example of the joint use of the conveyance-oriented facilities in one portion of a watershed and storage-oriented facilities in another portion. Another example of the combined use of the two approaches is to use conveyance-oriented facilities for the convenience system and storage-oriented facilities for the emergency system. The later approach is illustrated by the Skokie and Wilmette projects where the preexisting combined sewers are the convenience system and new street surface storage and underground tank storage constitute the emergency system. The convenience (minor) and emergency (major) systems are discussed in a later section of this chapter.

Historic Development of the Storage-Oriented Approach

Understanding of the status of stormwater management is informed by its history. Furthermore, to the extent that contemporary use of storage sometimes targets both the quantity and quality of stormwater, that history is very relevant to street storage and possible implication of street storage for control of nonpoint source pollutants. The following historical account is based on Walesh (1989, pp. 29-31) and other cited sources.

The original motivation for using the newer storage-oriented approach over the traditional conveyance-oriented approach was that the former offered cost advantages. Most documented examples of the cost advantage of the storage-oriented approach over the conveyance-oriented approach relate to newly developing areas (e.g., Poertner, 1974). More recently, however, there have been situations in which already developed areas are being retrofitted with a storage-oriented system at significantly less cost than that of a traditional conveyance-oriented system. Examples include the Skokie and Wilmette projects.

A complete comparison of conveyance-oriented and storage-oriented systems for a particular location must consider all costs and benefits, tangible and intangible. For example, reduction in developable land and possible safety hazards to children with the storage-oriented system are costs, while increased land values for areas contiguous to attractive storage facilities are a benefit. Cost analyses must be conducted on a case-be-case basis. Documented case studies and experience suggest that storage facilities should be at least considered for controlling the quantity of stormwater runoff because of the potential for cost savings.

After initial use of storage facilities for the single purpose of controlling the quantity of stormwater runoff, storage facilities found increased use as multiple-purpose developments. In addition to their primary surface water control function, storage facilities were designed to provide, or be part of, sites for recreation including such activities as fishing, boating, tennis, jogging, ski touring, sledding, and field sports. Well-planned, well-designed, and well-operated storage facilities were also found to have aesthetic value for contiguous and nearby residential areas.

In addition to the obvious erosion and sedimentation problems often associated with urbanization, studies conducted in the 1970's indicated that urban stormwater runoff contributes a significant part of some of the pollutants finding their way to surface waters. For example, an early study conducted in Durham, NC, compared the quality of urban runoff with that of secondary municipal sewage treatment effluent on the basis of weight per unit area per year (Colston, 1974). On an annual basis, the urban runoff contributed 91 percent of the chemical oxygen demand, 89 percent of ultimate biochemical oxygen demand, and 99 percent of the suspended solids.
Many measures were suggested for controlling urban area nonpoint-source pollution in general and erosion and sedimentation in particular. The use of storage was one of these measures. The state of the art of using storage facilities to control the quality of urban stormwater runoff is still under development.

In summary, storage facilities are being increasingly used for controlling the quantity of runoff because of the cost advantages and because of their recreation and aesthetic values. They are also being increasingly designed to accomplish a third function of controlling the quality of stormwater runoff.

The evolution of using the storage-oriented approach in surface water management is summarized in Figure 3-2. Beginning with the single quantity control function, storage facilities have evolved so that they now can serve three compatible functions: quantity control; recreation, aesthetic, and other supplemental uses; and quality control.

Street storage systems, which make heavy use of storage, have served the quantity control function as demonstrated by the Skokie and Wilmette applications. Street storage also has the potential to serve the quality control function relative to nonpoint source pollution. This possibility is discussed in Chapter 11.

Emergency and Convenience Systems

The increasingly accepted emergency and convenience system approach to stormwater management is an integral part of the street storage approach. Accordingly, a brief overview of the emergency-convenience system is provided. This overview is taken from Walesh (1989, pp. 31-34) and other cited sources.

The stormwater system may be thought of as two systems, one functionally and physically superimposed on the other. One system, the convenience or "minor" system, contains components that accommodate frequent, small runoff events. The other system, the emergency or "major" or overflow system, consists of components that control infrequent but major runoff events. Although many of the components are common to both the convenience and emergency system, their relative importance in the two systems varies significantly.

The Convenience (Minor) System

Stormwater systems have traditionally been designed to convey all the design runoff without street flooding, parking lot or other ponding, or basement backup associated with frequent, small runoff events—up to about the five- or 10-year recurrence interval—from an urban area with no damage and little or no disruption or even

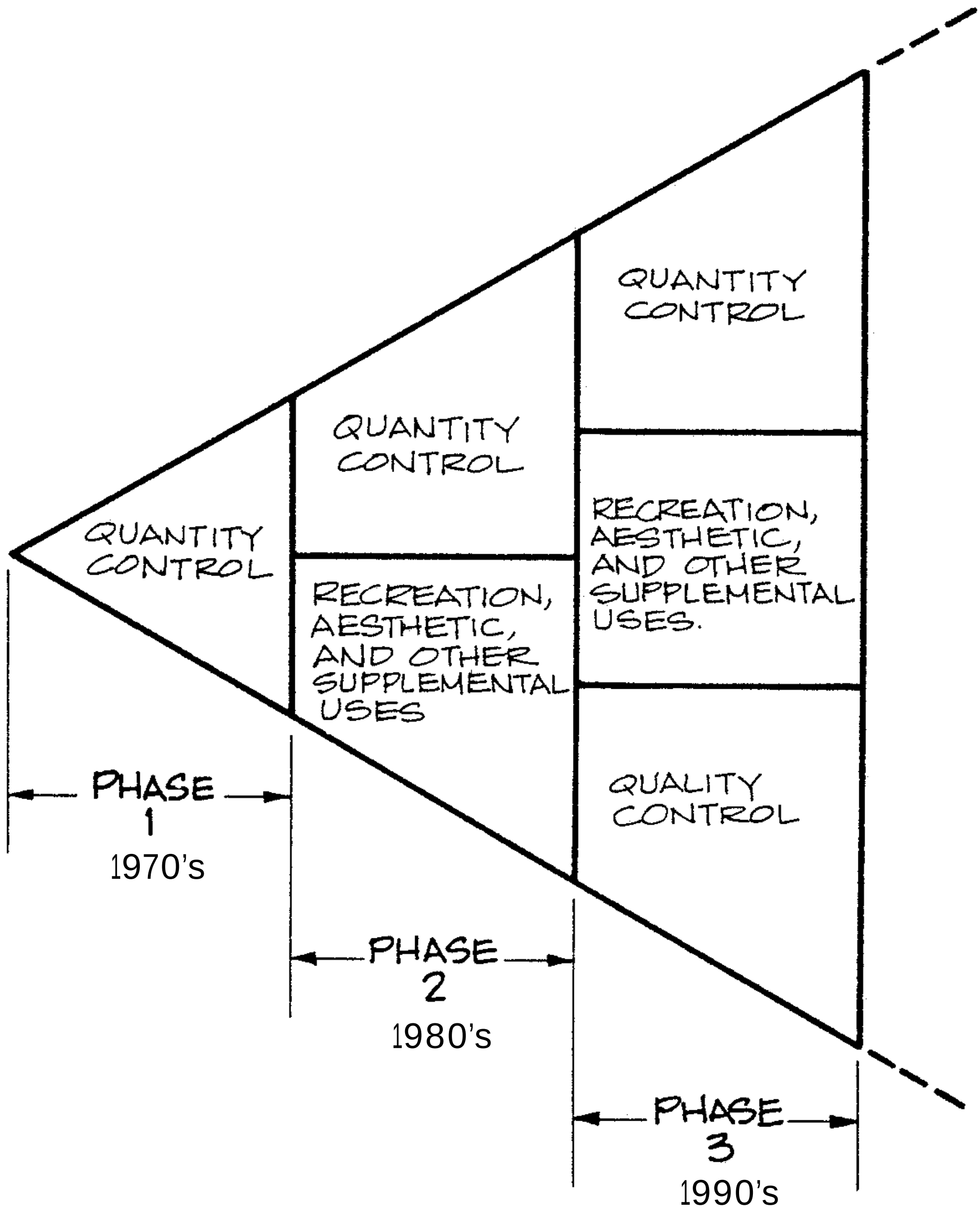


Figure 3-2. Historic development and use of storage facilities for stormwater management in the U.S. (Source: Walesh, 1989, p. 31).

unimportant.

The Emergency (Major or Overflow) System

Major runoff events—such as 50- or 100-year recurrence interval events—will also inevitably occur in urban areas. Accordingly, some stormwater control systems are designed to control major event runoff rates and volumes in such a manner that although temporary disruptions and inconvenience will occur, widespread danger and damage will be avoided. This is accomplished by allowing for temporary storage and conveyance of stormwater on parking lots and streets, within public open space areas, and in other suitable low-lying areas; by establishing building grades well above street grades; and by designing streets and roadways to serve as open channels providing for the temporary storage and conveyance of runoff as it moves through the urban area toward a safe discharge point.

The emergency system is sometimes called the major system because it is designed to control runoff from "major" rainfall events. Sometimes the emergency system is referred to as the overflow system because it is the system that begins to function when the capacity of the convenience system is exceeded and it overflows.

Most surface water control systems, however, are not explicitly designed to accommodate major runoff events. Nevertheless, major runoff events occur and the emergency system will, by default, function during such events with sometimes catastrophic damage and disruption.

Combined Convenience and Emergency System

The ideal surface stormwater system is planned and designed to include both the emergency and convenience systems in anticipation of the inevitable occurrence of both major and minor runoff events. In a combination system, essentially complete control of minor runoff events is achieved to minimize disruption and damage during smaller, frequently occurring rainfall events. Emergency components of the system are designed to accept some temporary disruption and inconvenience during relatively infrequent events. Jones (1967) provided a very readable and convincing early explanation of the convenience-emergency system concept.

Figure 3-3 illustrates the emergency and convenience system concept applied to a typical urban street cross section. This is essentially the manner in which the emergency system appears in the street storage system described in this report. The variation is that with street storage system, the receiving sewer is a combined sewer—not a separate storm sewer. Figure 3-4 illustrates the emergency and convenience system applied to a channel-floodplain passing through an urban area.

Components in the stormwater system can be examined from the perspective of whether or not they function, how they function, and the relative importance of their functioning under both convenience and emergency conditions. Consider, for example, stormwater inlets located along the curbs and gutters of urban streets. For minor runoff events, such inlets are normally designed to pass essentially all the discharge conveyed to them, but under major events they should be expected to intercept only a small portion of the flow moving along the gutter. Thus, whereas inlets are key elements in a convenience system, they are of little importance in an emergency system.

Note, however, that catch basins—inlets with sumps—are of great importance in the Skokie and Wilmette street storage systems. Their operation is not left to chance. Flow regulators are installed in the catch basins.

Streets are graded longitudinally and laterally to provide, during minor runoff events, for rapid runoff of stormwater to curbs and inlets or to roadside ditches. During major events, however, the longitudinal slope of the streets and the relative elevation of the streets and contiguous residences and commercial and industrial structures must be designed such that the street functions as a large, paved open channel or reservoir which temporarily conveys or stores stormwater runoff. Thus, whereas the street is one of many components in a surface water system during minor runoff events, it becomes a key element in the surface water system during major events.

Streets are certainly key elements in the street storage systems described in this report. However, unlike the situation in the design of new development, the basic topography of the streets and contiguous areas is already defined. It provides a physical constraint within which the street storage system must be designed. That design includes some refinements in the topography in the form of street berms.

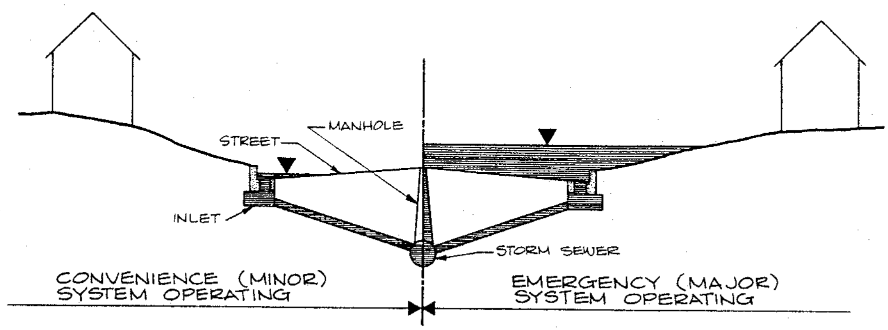


Figure 3-3. Emergency and convenience system applied to an urban street (Source: Walesh, 1989, p. 33).

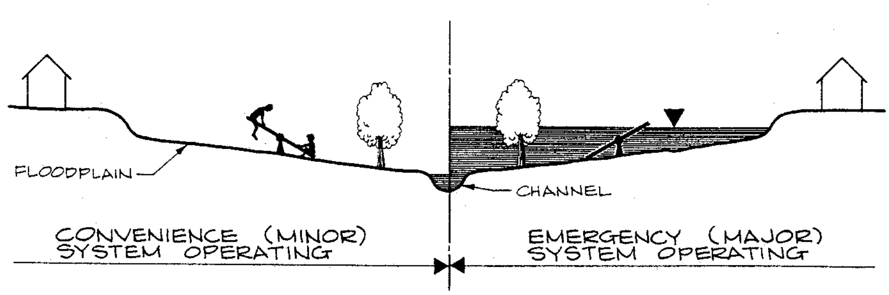


Figure 3-4. Emergency and convenience system applied along a channel and floodplain (Source: Walesh, 1989, p. 33).

Stormwater storage facilities have, as described in the preceding section, proven to be technically sound, economically attractive, and environmentally acceptable elements in urban stormwater management systems. However, they have been used primarily as preventive measures in newly developing areas in contrast with use as remedial measures in developed areas.

Widespread, frequent—one or more times per year—basement flooding is common in existing, old, and intensely developed urban areas, served by CSSs. Traditional and proven remedial measures to CSS basement and surface flooding problems include, as noted in Chapter 1, separation and in-system storage of combined sewage.

A fundamentally different alternative to remedying combined sewer surcharging and surface flooding is retrofitting the existing system to include storage. More specifically, it is feasible under certain conditions to implement a carefully engineered system of surface and sub-surface storage facilities to control the rate at which stormwater flows into the combined sewer system so it does not exceed the capacity of the existing sewers, thereby mitigating basement and other flooding.

The largely implemented Skokie and Wilmette projects have demonstrated the technical and economic feasibility of retrofitting stormwater storage into CSSs. Furthermore, retrofitted stormwater storage can also have other benefits such as reducing peak flows of combined sewage to regional wastewater agencies, mitigating inflow to SSSs, solving flooding problems in separate sewer systems, and managing nonpoint source pollution.

Retrofitting is not limited to CSSs. It can also be applied to the stormwater portion of separate sewer systems for purposes such as improving quantity and/or quality control, reducing safety hazards and enhancing recreation facilities and aesthetic values. Retrofitting stormwater facilities has been explored by and reported on by Walesh (1991, 1992, 1993 and 1998).

Distinction Between Analysis and Design: Diagnosis and Then Prescription

An important integrating theme of this chapter is describing, using mainly case studies, tools and techniques for ***analyzing*** the root causes of problems in CSSs and ***designing*** solutions to these problems. A medical analogy helps to appreciate the difference between analysis and design. Analysis in engineering, like diagnosis in medicine, strives to get beyond symptoms. In medicine, symptoms may be a fever or pain. In CSSs, symptoms may be flooded basements or overflows into surface waters. In both medicine and engineering, symptoms may appear to be problems or, in fact, be problems to those who are adversely affected, but they are not the root causes. In medicine, the cause of fever may be an infection and in engineering the cause of a symptom like basement flooding may be inadequate flow carrying capacity of selected sections of combined sewers.

Once the medical diagnosis or engineering analysis has gotten beyond symptoms to causes, remedies or solutions can be explored. Medical doctors prescribe solutions and engineers design solutions.

Walesh (1989, p. 317) elaborates on this two step analysis and design, or diagnosis and prescription, process. His discussion is directly applicable to CSSs. Two fundamental questions must be addressed in all but the most trivial CSSs. First, how does the existing system function, that is, what is the cause or what are the causes of the CSS problems such as basement flooding, surface flooding and CSOs? This, the problem definition phase, must use but look way beyond and below symptoms such as the number of basements flooding, the location of street inundation, and the frequency of overflows. The first step, that is, the analysis or diagnosis phase, focuses on finding causes. A clear understanding of the cause of a problem tends to lead to its solution.

The second fundamental question is: How can the CSS be modified or altered to eliminate or mitigate the causes of the problems and to prevent similar or new problems from occurring in the future? The process of answering this question may be called design or prescription.

Why the emphasis on the two part analysis and design, or diagnosis and prescription process? Answer: CSSs are complex and there is a tendency to rush to judgement as to causes so that a community can “get on” with implementing solutions. Furthermore, there is also a pattern, as shown by the Skokie and Wilmette studies discussed in Chapter 2, to favor, if not exclusively consider, traditional solutions to CSS problems. Superficial analyses combined with a predisposition to employ traditional solutions can lead to unnecessarily costly solutions to CSS problems.

Ideas and information presented in this chapter are intended to show the long term value of a careful, deliberate, multi-faceted (e.g., monitoring, computer modeling, pilot studies) analysis and design process. The “pay off” for a community can be a cost-effective solution to its CSS problems.

Chronological Mode of Presentation

The remainder of this chapter is structured in a chronological fashion. Using Skokie, Wilmette and, occasionally other communities, the steps that may be needed to implement a street storage system are described in the approximate order they would occur. Figure 3-5 illustrates the overall process. The description begins with the understanding of the concept of a street storage system and concludes with

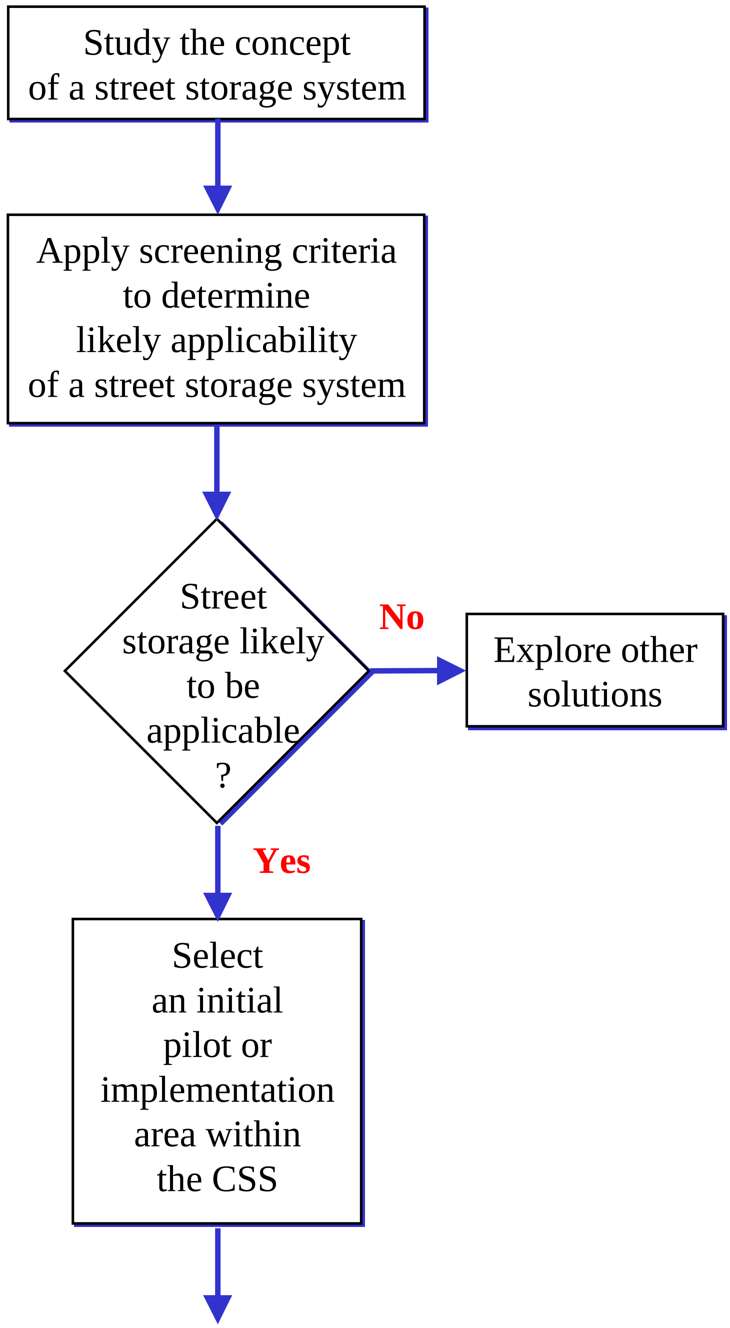


Figure 3-5 (1 of 2). Successful application of a street storage system requires a systematic analysis and design process that begins with understanding the concept and concludes with construction.

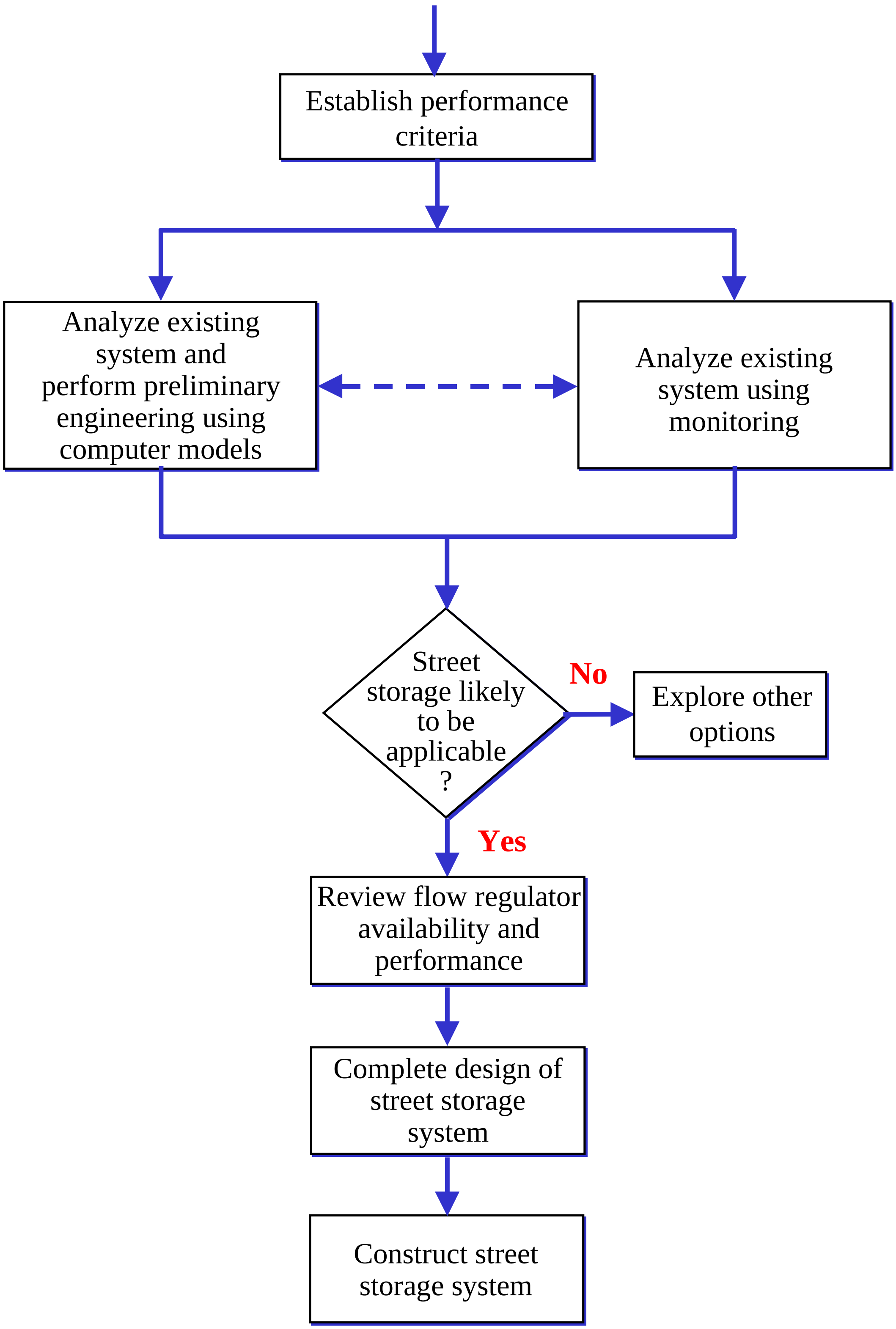


Figure 3-5 (2 of 2). Successful application of a street storage system requires a systematic analysis and design process that begins with understanding the concept and concludes with construction.

constructing the system.

All of the steps followed in Skokie, the first large scale application of street storage, are not likely to be needed in other communities. For example, the laboratory and field testing of various flow regulators that was necessary for the Skokie project would probably not be needed in other applications. However, the Skokie laboratory and field testing is fully described here so that the process and especially the results are available for possible use by others.

The Concept of Street Storage

Fundamental to understanding the street storage system concept is appreciating the capacity of urban streets to carry and store stormwater. Accordingly, this section begins with discussions of the flow capacity and the storage capacity of an urban street. Figure 3-6 shows one photograph of a typical asphalt covered street in Skokie and a typical brick street in Wilmette. These photographs suggest the potential stormwater conveyance and storage functions of urban streets.

Conveyance Capacity of Urban Streets

Urban streets can be a vital element in the previously described emergency stormwater system by conveying stormwater to a safe discharge point during a major rainfall-runoff event. The Manning open channel flow equation is available for calculating depth versus discharge relationships for urban streets.

Street Cross Sections

Some Skokie street cross sections, including the adjacent parkway, sidewalk and lawn up to the street side of residences, are shown in Figure 3-7. A typical half cross section of a street, based in part on the configurations of the actual street cross sections shown in Figure 3-7, is presented in Figure 3-8. Longitudinal slopes, S_o, of 0.1, 1.0, and 3.0 percent are assumed for the subsequent analysis.

Analysis Procedure

The objective is to determine, assuming normal depth, the flow capacity of the street cross section for a range of depths and a range of longitudinal slopes. The total flow in the half section can be determined as the sum of the flow in subsection A of Figure 3-8, the street portion of the cross section, and subsection B, the lawn portion of the cross section. With this approach, the Manning equation becomes

Figure 3-6. The photographs of urban streets in Skokie (top) and Wilmette (bottom) suggest their potential stormwater conveyance and storage function.

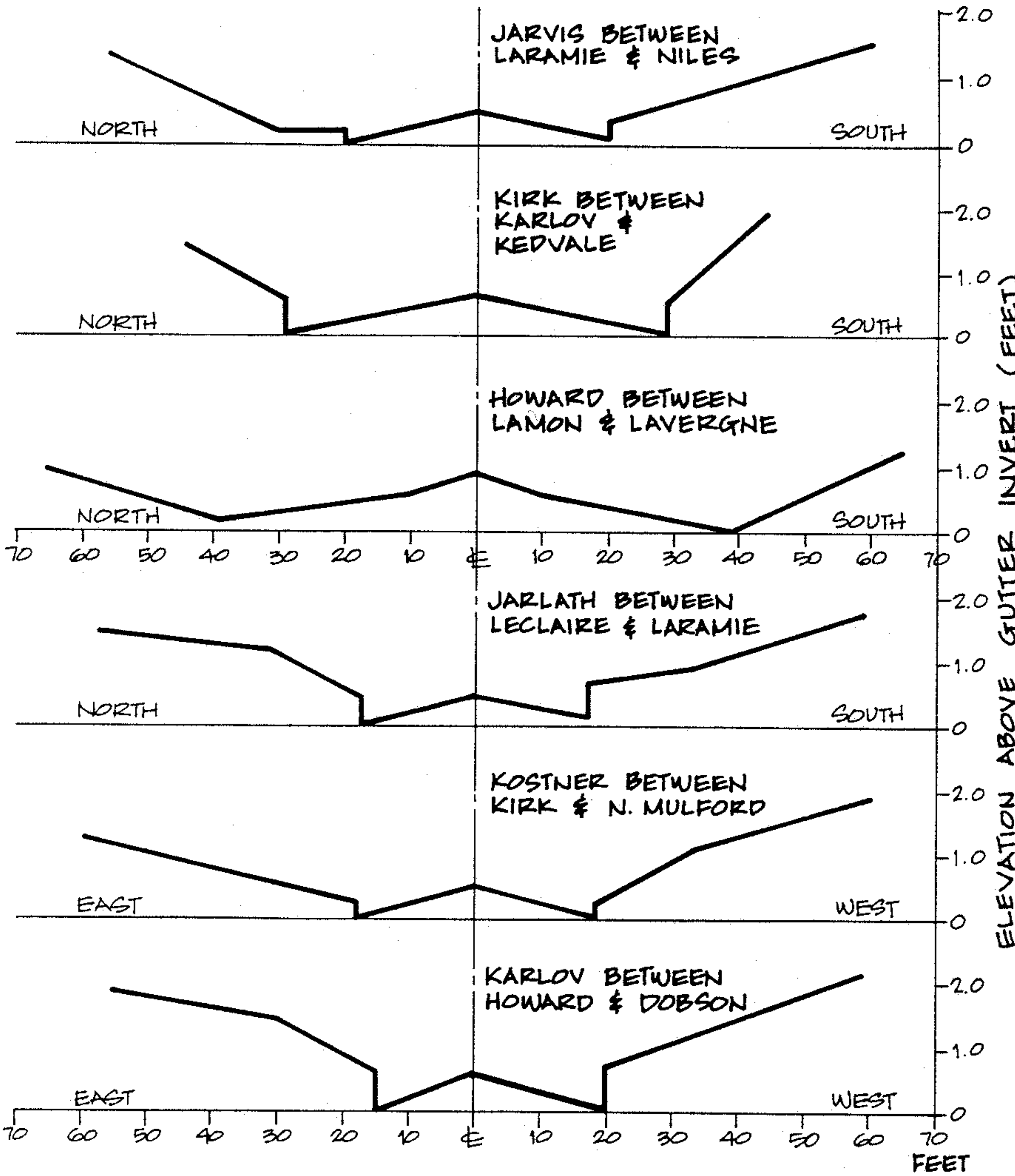


Figure 3-7. Selected street cross sections from Skokie, IL (Source: Donohue, 1982b, p. 65)

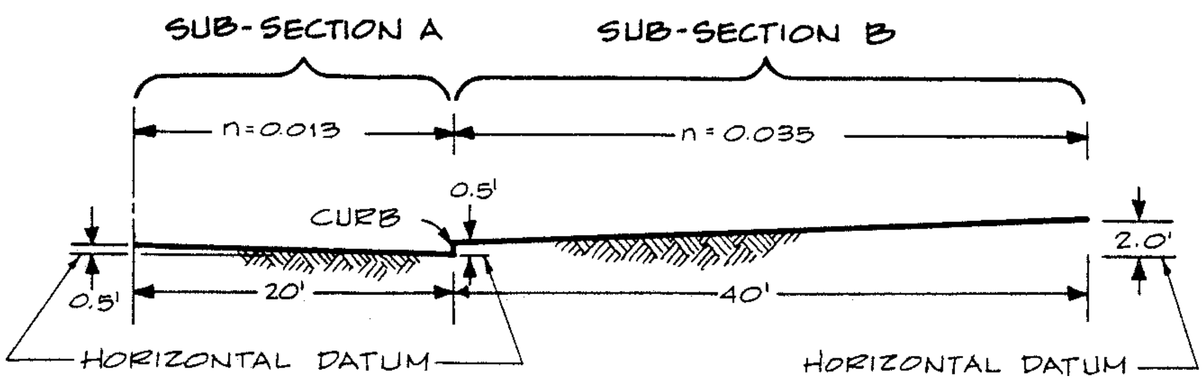


Figure 3-8. Typical street and lawn cross section representative of actual Skokie cross sections (Source: Walesh, 1989, p. 191).

$$Q = Q_A + Q_B = 1.49 S_0^{0.5} \left(\frac{A_A R_A^{2/3}}{n_A} + \frac{A_B R_B^{2/3}}{n_B} \right)$$

where Q_A = discharge in subsection A
Q_B = discharge in subsection B
S_o = longitudinal slope for both subsections (dimensionless)
A_A = flow cross-section area in subsection A
R_A = hydraulic radius for subsection $A = A_A / P_A$, where P_A = the wetted perimeter
n_A = Manning roughness coefficient for subsection A
A_B = flow cross-sectional area in subsection B
R_B = hydraulic radius for subsection $B = A_B / P_B$, where P_B = the wetted perimeter
n_B = Manning roughness coefficient for subsection B

Assume the depth of flow at the gutter of 0.5 ft. Then

$$A_A = (0.5)(0.5)(20) = 5\,ft^2$$

$$P_A = 0.5 + \left(20^2 + 0.5^2\right)^{0.5} = 20.5\,ft$$

$$R_A = \frac{5}{20.5} = 0.244\,ft$$

$$A_B = 0$$

$$Q = Q_A + Q_B = 1.49 S_0^{0.5} \frac{\left(5 \times 0.244^{2/3}\right)}{0.013} + 0 = 224 S_0^{1/2}$$

Substituting S0 = 0.1, 1.0, and 3.0 percent yields half-street discharges of 7.1, 22.4, and 38.8 ft^3/sec, respectively. The corresponding average velocities are, 1.42, 4.48, and 7.76 ft/sec, respectively. The preceding process is repeated for depths at the gutter of 1.0 and 2.0 ft.

Results

Depth versus discharge relationships for the complete street cross section, including adjacent lawns, are summarized in graphic form in Figure 3-9. A separate curve is presented for each of the three longitudinal slopes.

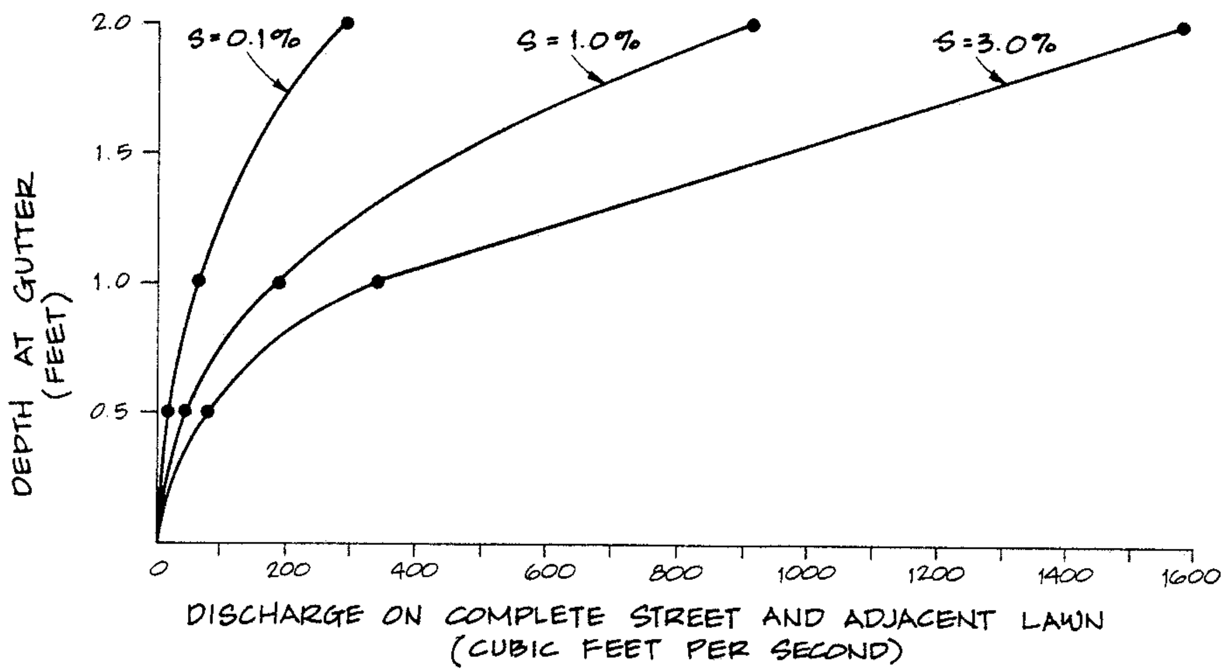


Figure 3-9. Depth versus discharge relationships for typical street and lawn cross sections (Source: Walesh, 1989, p. 192).

The analysis indicates that streets can carry very large flows relative to typical storm sewers at similar slopes. For example, consider the case with a depth at the gutter of 1.0 ft. For the three longitudinal slopes, flows on the full width of street and adjacent lawn areas are approximately 14 to 18 times greater than those that would be carried in a 24-inch diameter reinforced-concrete pipe laid at the same slope and flowing full.

The preceding analysis suggests that better use could be made of streets by designing them to be channels that function as part of the emergency stormwater system. Using streets for temporary stormwater conveyance is one aspect of the street storage system.

Storage Capacity of Urban Streets

Urban streets can also constitute a vital element in the emergency stormwater system by temporarily storing stormwater until it can be safely discharged to storm or combined sewers. Actual street cross sections shown in Figure 3-7 suggest the volume of storage available.

Analysis Procedure

Consider again the typical street cross section presented in Figure 3-8 and cross sectional areas calculated and presented in the previous section titled "Conveyance Capacity of Urban Streets." A plan view of a typical single-family residential area with paved streets and curb and gutter is shown in Figure 3-10.

Consider the east half of the 600-ft-long section of Easy Street and the directly tributary area of 67,500 ft^2. The runoff coefficient for the area is 0.5; that is, half of the rainfall on the total tributary area is directed toward the east half of Easy Street.

Assuming that the street has a zero longitudinal slope, the cross-sectional area of the east side of the street and cumulative storage on the east side of the street may be calculated as a function of depth of water relative to the gutter. Results are presented in Table 3-1 and Figure 3-11. The depth versus volume relationship for the east side of the 600-ft-long street has a shape similar to the depth versus volume relationship for a natural river valley. That is, as depth increases, the relative volume of incremental storage per unit of depth increases at least over the first one foot of depth.

Assume rainfall amounts of 0.5, 1.0, 2.0, and 4.0 in., which may be typical of moderate to very severe rainfall events. Assuming that half of the rainfall is directed to and remains in the street, the depth versus storage relationship presented in Figure 3-11 can be used to determine the depth of ponded water or each rainfall amount. The results are presented in Table 3-2.

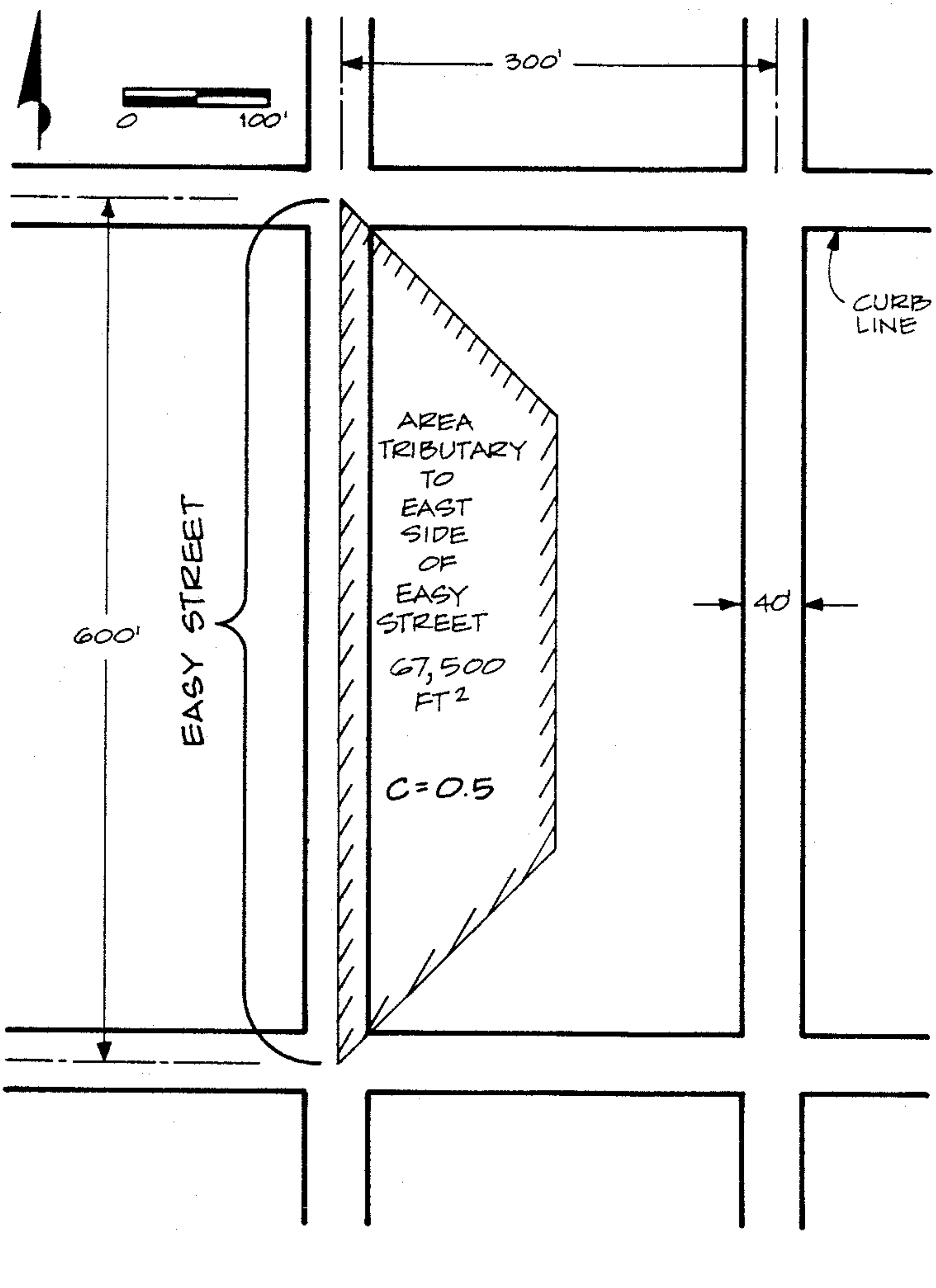


Figure 3-10. Typical urban street plan showing the area tributary to the east side of a one block segment of Easy Street (Source: Walesh, 1989, p. 193).

Table 3-1. Depth, cross-sectional area, and cumulative volume data for half of Easy Street (Source: Walesh, 1989, p. 194).

Depth at Gutter (ft)	Cross-Sectional Area on East Side of Street (ft^3)	Cumulative Storage on East Side of Street[1]	
		(ft^3)	(acre-ft)
0.0	0.0	0	0
0.5	5.0	3,000	0.07
1.0	18.33	11,000	0.25
2.0	65.00	39,000	0.90

1) for 600-ft. street segment and assuming zero longitudinal grade.

Table 3-2. Rainfall and depth of ponding for Easy Street[1] (Source: Walesh, 1989, p. 194).

Rainfall (in.)	Runoff		Depth of Ponding in Street Relative to Gutter (ft.)
	(in.)	(ft^3)	
0.50	0.25	1,410	0.30
1.00	0.50	2,810	0.45
2.00	1.00	5,625	0.75
4.00	2.00	11,250	1.00

1) Assumes zero longitudinal grade.

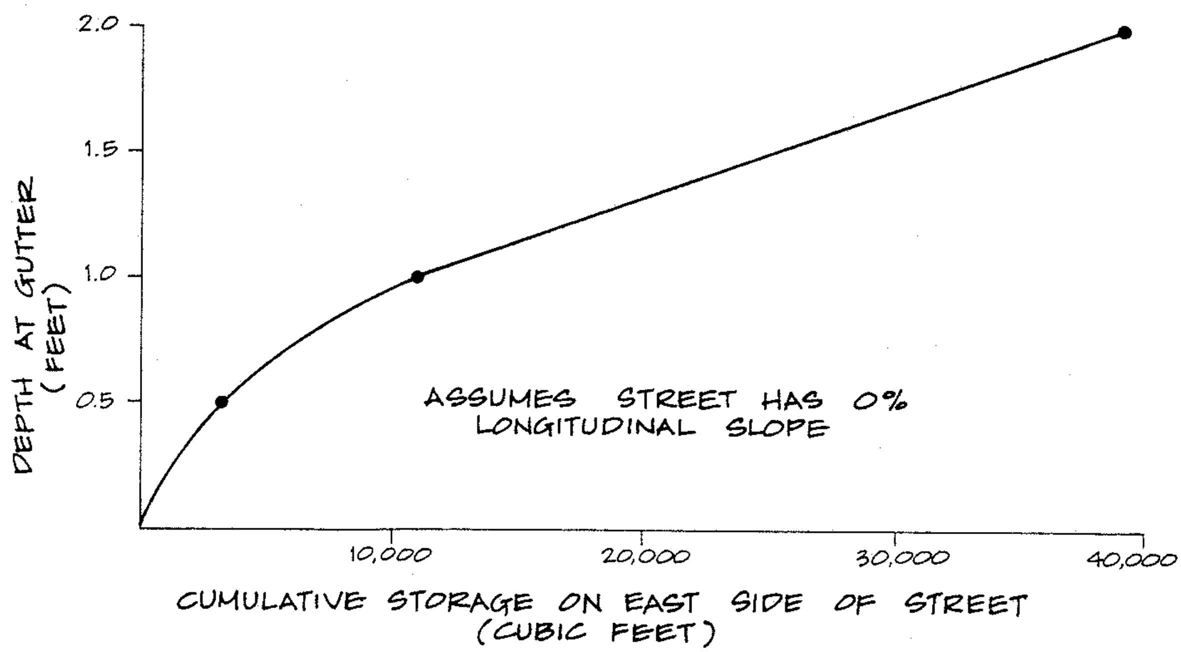


Figure 3-11. Depth versus volume relationship for Easy Street and lawn cross section (Source: Walesh, 1989, p. 194).

Results

As indicated, even with four inches of rainfall, and assuming that two inches of runoff is stored in the street, the peak depth of street ponding relative to the gutter would be one foot.

The simple analysis suggests that streets with low longitudinal grades have the capacity to store large volumes of stormwater runoff. Situations may arise where new streets can be designed to store stormwater, or existing streets can be retrofitted to serve a storage function as part of the emergency system. The latter retrofitting idea is one aspect of the street storage system.

Using Street Storage and Conveyance Capacity in Combined Sewer Systems

Attention now turns to CSSs. As briefly noted in Chapter 1, wet weather problems in CSSs, such as basement flooding, street flooding, and CSOs, are caused by peak rates of stormwater runoff, not necessarily by the runoff volumes. Midwestern experience suggests that wet weather flooding and pollution problems would often not occur, or would be much less severe, if the peak flows of stormwater could be lessened. Peak flows are often the principal culprit, not the volumes of stormwater runoff.

This suggests a fundamentally different approach having the following premise: reduce the peak flow rates of stormwater before it enters the combined sewer system. Accept the full volume of stormwater into the stormwater runoff into the CSS, but greatly reduce the peak rate of entry. Figure 3-12 illustrates, in conceptual fashion, this stormwater-oriented approach to reducing surcharging in CSS and, therefore, mitigating flooding and pollution.

But where and how can stormwater runoff be temporarily stored and otherwise controlled to reduce peak flows into the CSS? Urban streets have significant storage and conveyance capacity, as just illustrated, in this chapter. That storage capacity and conveyance capacity can be effectively utilized to answer the question of where and how to temporarily store stormwater.

Because of their storage capacity, some streets can be used to temporarily store stormwater before it mixes with sanitary sewage and surcharges the CSS. Because of their conveyance capacity, other streets can be used to convey stormwater from street segments with low surface storage capacity to street segments with high surface storage capacity. Streets in effect become a rectilinear conveyance and storage system that are activated under emergency conditions, that is, when the capacity on one or more segments of the CSS is exceeded.

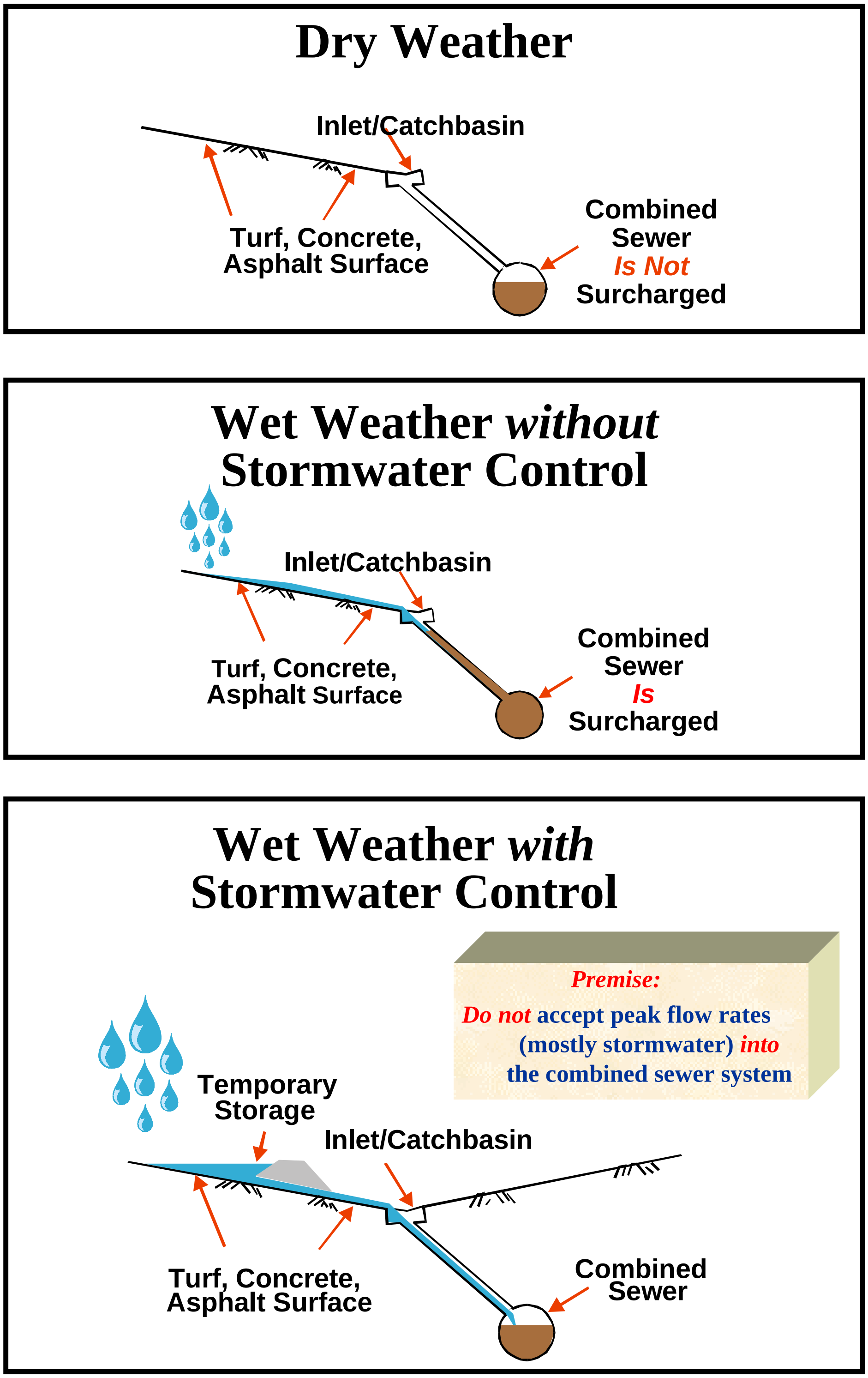


Figure 3-12. Control of peak rates of stormwater runoff can, in concept, mitigate surcharging of combined sewer systems.

Bringing the Street Storage Concept to Reality: Berms, Flow Regulators, and Subsurface Storage

Capitalizing on street storage and conveyance capacity requires three elements that operate in a integrated fashion. These elements are berms, flow regulators and subsurface tanks. In this section, first berms and then regulators are described. Their integrated function is then explained. Finally, subsurface storage facilities, which also use regulators, are discussed.

Berms

Berms Contrasted With Bumps and Humps

A berm is a low structure constructed across a street, from curb to curb, and intended to temporarily impound water on its upstream side. The crest or top of the berm, when viewed along the longitudinal axis of the street, is horizontal. It is, in effect, a spillway.

Figure 3-13 is a photograph of a mid-block berm in Skokie. The berm is identified by the asphalt overlay. A berm that lies across a Skokie intersection is shown in Figure 3-14. This berm may also be identified by the asphalt overlay. A berm under construction is shown in Figure 3-15. The construction process typically consists of:

- Relocating inlets, if needed.
- Raising the curb and gutter, which has been done in Figure 3-15.
- Milling the street surface. The concrete has been milled in Figure 3-15.
- Placing lifts of asphalt to form the berm. At least one lift has been placed in Figure 3-15.

The term berm was selected early in the Skokie street storage project to distinguish it from bumps and humps, two established types of vehicle speed control devices. The essential features of bumps, humps and berms are illustrated in Figure 3-16.

According to the Institute of Transportation Engineers (1997, p. 1):

Figure 3-13. Mid-block berm in Skokie intended to direct the flow of stormwater runoff.

Figure 3-14. Berm across an intersection in Skokie.

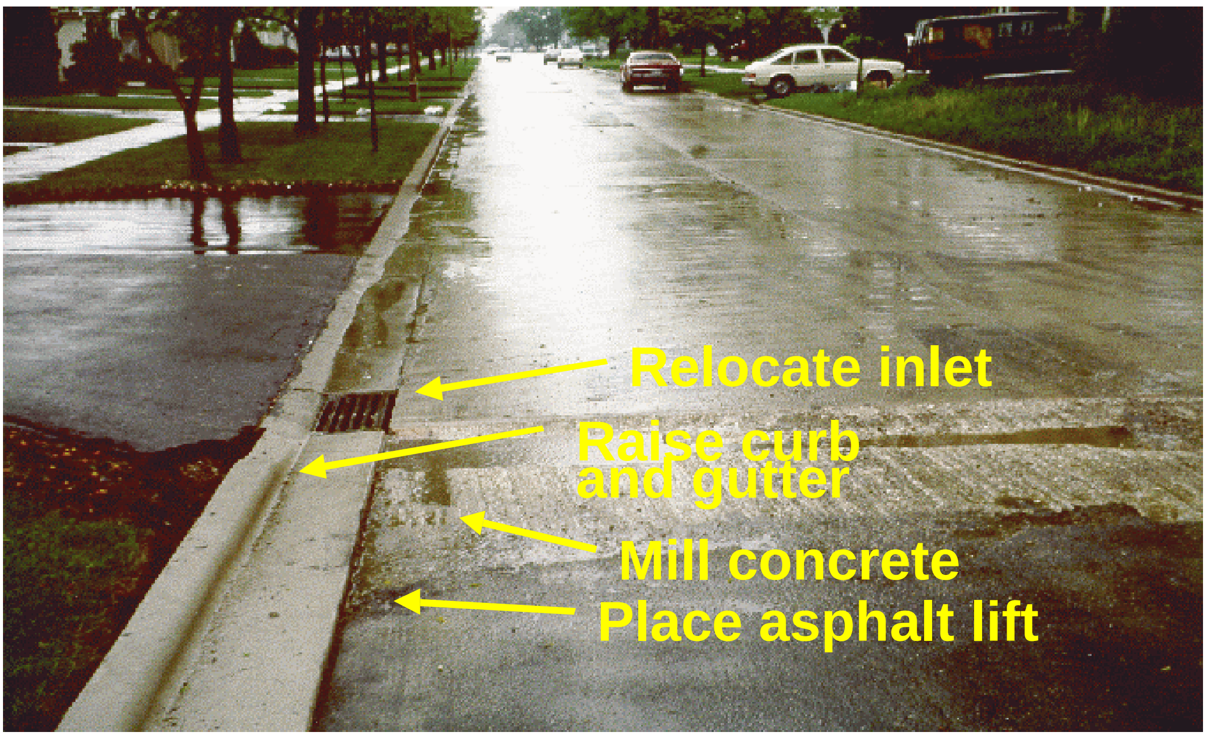


Figure 3-15. A berm under construction in Skokie showing relocated inlet, raised curb and gutter, milled concrete surface and an asphalt lift.

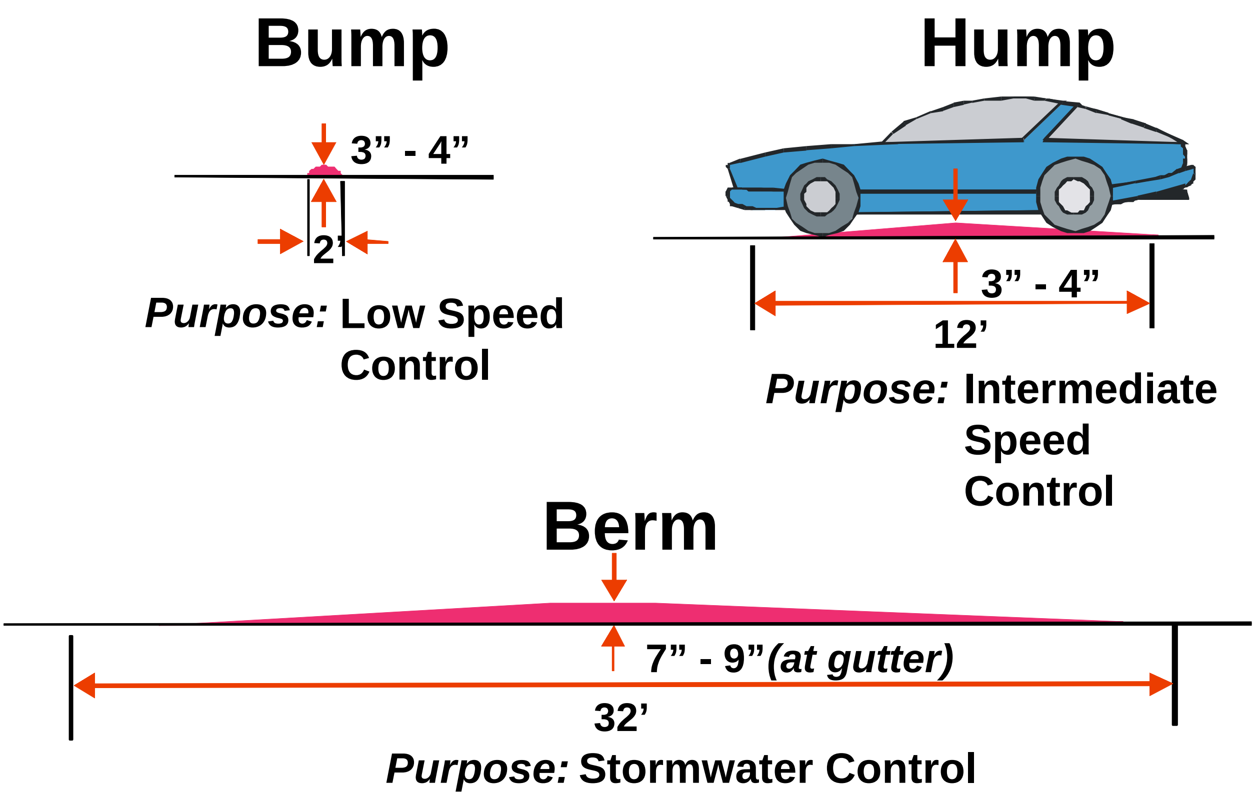


Figure 3-16. Bumps and humps are vehicle control devices and the gentler berm is a stormwater control device.

> *of three to six inches with a length (in the direction of vehicle movement) of one to three feet. Speed bumps are typically found on private roadways and parking lots and do not tend to exhibit consistent design parameters from one installation to another... A bump causes significant driver discomfort at typical residential speeds and generally results in vehicles slowing to five mph or less at the bump.*

Also, according to the ITE (1997, p. 1):

> *A speed hump is a raised area in the roadway pavement surface extending transversely across the travel way... speed humps normally have a maximum height of three to four inches with a travel length of approximately 12 feet... Within typical residential speed ranges, humps create a gentle vehicle rocking motion that causes some driver discomfort and results in most vehicles slowing to 15 mph or less at each hump and 25 to 30 mph between properly spaced humps in a system.*

Some speed humps have a flat top, that is, a plateau shape with gradual approaches on both ends. This configuration tends to protect long wheel base vehicles like fire trucks (Velazquez, 1992). Recognizing that speed humps control vehicle speeds without the presence of police personnel, the humps have been called “sleeping policemen” (ITE, 1997, p. 1).

In the interest of more fully understanding speed humps, consider their benefits and drawbacks, as noted by Elizer (1996), and Haynes (1998). Some of these positive and negative features can also be applied to berms when they are viewed from a vehicular perspective.

Principal speed hump benefits are:

1. Reduced vehicle speeds.
2. Less accidents.

3. Diversion of traffic to more desirable routes; for example, from a local street being used as a short cut to an arterial street.
4. Less traffic noise with the possible exception of more noise from trucks.
5. Less air quality impact and energy use than stop signs.
6. Support by most local residents.

Some speed hump drawbacks include:

1. Undesired traffic diversions; for example, from arterial to local streets.
2. Interference with the rapid response of police, firefighters, paramedics and other emergency vehicles.
3. Negative aesthetic impact of humps and related signs and markings.
4. Concern with street sweeping and plowing, ice formation and other maintenance and repair functions.
5. Fear of increased liability exposure attributed to claims of vehicle damage and injury to bicyclists.
6. Poor design and construction resulting from the misperception that humps are simple. ITE (1997) provides detailed design guidance.

Given the possible benefits and drawbacks to speed humps, some municipalities have taken a systematic approach to optimize their use. During the 1994 to 1997 period, 217 people were killed in automobile crashes in Montgomery County (Haynes, 1998). Accordingly, the county installed more than 1000 humps on 300 residential streets as a partial solution to the excessive number of automobile accidents. Thousand Oaks, CA, which is one of the first U.S. cities to use speed humps, installed them and studied their effects. Their conclusion: if the hump is more than two inches high, drivers will seek alternate routes (Velazquez, 1992). Boulder, CO addressed the issue of interference with emergency vehicles by banning speed humps on emergency routes (Haynes, 1998).

Berms: The Negative Perception Problem

The suggestion of building structures across streets to control stormwater often elicits negative reactions, especially from engineers and other personnel responsible for the design, construction and maintenance of streets. The driving public may also express concern. One way to deal with this is to note that across street structures are commonly used in urban areas to control the speed of vehicles. For example, ITE (1997, p. 5) provides a “partial listing of jurisdictions with speed hump experience” in the United States and Canada. Included in the partial list are 52 communities in 17 states and three provinces. (ITE (1997, p. 5) also notes that speed humps are also used in at least 14 countries outside of the U.S. In other words, humps, engineered cross-street structures, are widely used in the transportation field.

Note that a berm has a much gentler slope than a hump in the direction of travel.

Accordingly, berms cause even less discomfort than humps. Clearly, berms are vastly different than bumps when measured in terms of driver discomfort.

The Possibility of Integrating Stormwater Berms and Speed Hump Functions

Although the berms, as used extensively in Skokie and Wilmette, differ markedly in function from the humps used widely in traffic control, berms and humps are very similar in form. This suggests that traffic engineers and other personnel responsible for urban streets should be receptive to the idea of using berms to control stormwater. In fact, the convergence of the stormwater berm and the speed hump suggests the possibility of retrofitting existing urban areas with these simple structures for the dual purposes of stormwater and traffic control. Going one step further, convergence of the form and function of berms and humps opens the possibility of designing these structures into new urban development to optimize stormwater and traffic management.

The previously mentioned ITE (1997) document is described as a recommended practice of the ITE. Interestingly, the only mention of stormwater in this document is a brief caution to not interfere with drainage. More specifically, ITE (1997, p. 20) states:

> *Speed humps should be installed with appropriate provisions made for roadway drainage... Ideally, a hump should be installed immediately on the downside of an existing drain inlet. If this is not feasible the construction of a bypass drain or other treatment to route water around the hump should be considered.*

On the more positive side, and in keeping with the idea integrating stormwater berms/speed hump structures into new development, ITE notes that speed humps could be designed into new streets. The guidelines state (ITE, 1997, p. 27):

> *It is desirable in the planning of new residential subdivisions to configure and design local streets to minimize excessive speed, excessive volumes, and cut-through traffic from outside the immediate neighborhood. However, where adequate subdivision planning and street design control cannot be achieved, and one of the aforementioned problems is considered likely, it may be appropriate to include speed humps as part of new street construction after consideration of less restrictive design or traffic*

> *control techniques.*

Flow Regulators

For purposes of this manual, a flow regulator is a passive, gravity device that regulates the flow of stormwater into a combined sewer. Because it restricts flow, a flow regulator must be designed in combination with storage which is usually located immediately upstream.

Donohue (March 1984a, p. 3-1) identifies three common features of flow regulators:

> *A common feature of flow regulators is that they are gravity devices operating without external energy sources or external control. That is, they are intended to be simple devices requiring no control and minimal attention.*
>
> *A second characteristic shared by most flow regulators is that they are designed and installed to achieve the desired flow reduction while minimizing the likelihood of blockage by debris relative to that which could occur with a conventional orifice. Some flow regulators result in less flow passing the control section for a given head or head range than would occur with a simple orifice.*
>
> *A third feature of flow regulators is the need to specify three parameters for design. The first parameter is the maximum discharge and the second parameter is the corresponding design head. The third parameter is installation requirements such as available space and expected orientation of the device.*

Many flow regulators have been developed and tested. A discussion of the configuration and performance of various flow regulators appears later in this chapter. For the purposes of this section, flow regulators are viewed as a generic device having the preceding three features.

As further explained by Donohue (March 1984a, p. 3-1), “flow regulators may be installed in a variety of locations in an urban stormwater-wastewater system including: in storm inlets and catch basins to cause temporary ponding on streets or in depressed areas; at the outlets of subsurface and surface detention facilities to induce temporary subsurface and surface storage; and within ...sewers to utilize available in-system storage."

The meaning of the terms inlet and catch basin, as used for example in the preceding paragraph, are important for purposes of this report. As explained by Donohue (March 1984a, p. 3-1):

> *Inlets collect runoff from the land surface and discharge via a pipe. Inlets do not have a sump. That is, the discharge pipe is at the bottom of the inlet. Catch basins receive flow from inlets and, occasionally, directly from the land surface and discharge to the sewer system. Catch basins have a sump created by the outlet pipe being several feet above the bottom of the basin. This sump serves to trap leaves and other debris and requires periodic removal and cleaning.*

A typical Skokie configuration of an inlet, a catch basin and a manhole on a combined sewer is shown in Figure 3-17. The configuration is shown in plan and section. Note that, in a properly operating system, the transition from stormwater runoff to combined sewage occurs in the pipe connecting the catch basin to the manhole. A trap, as shown in Figure 3-17, is required to prevent sewer gases from being a problem near the catch basins.

Figure 3-18 uses a flow regulator installed in a catch basin to illustrate the regulator's function. Comparison of the two head-discharge relationships indicates that for any given head on the catch basin outlet, the flow regulator results in significantly less flow out of the catch basin. This flow restriction or reduction must be accomplished without blocking of the flow regulator with debris carried by the stormwater.

Although the function of a flow regulator is illustrated in Figure 3-18 using a catch basin installation, flow regulators can be installed in other places. Example locations, as noted earlier, are in stormwater inlets and at the outlets of surface and subsurface storage facilities.

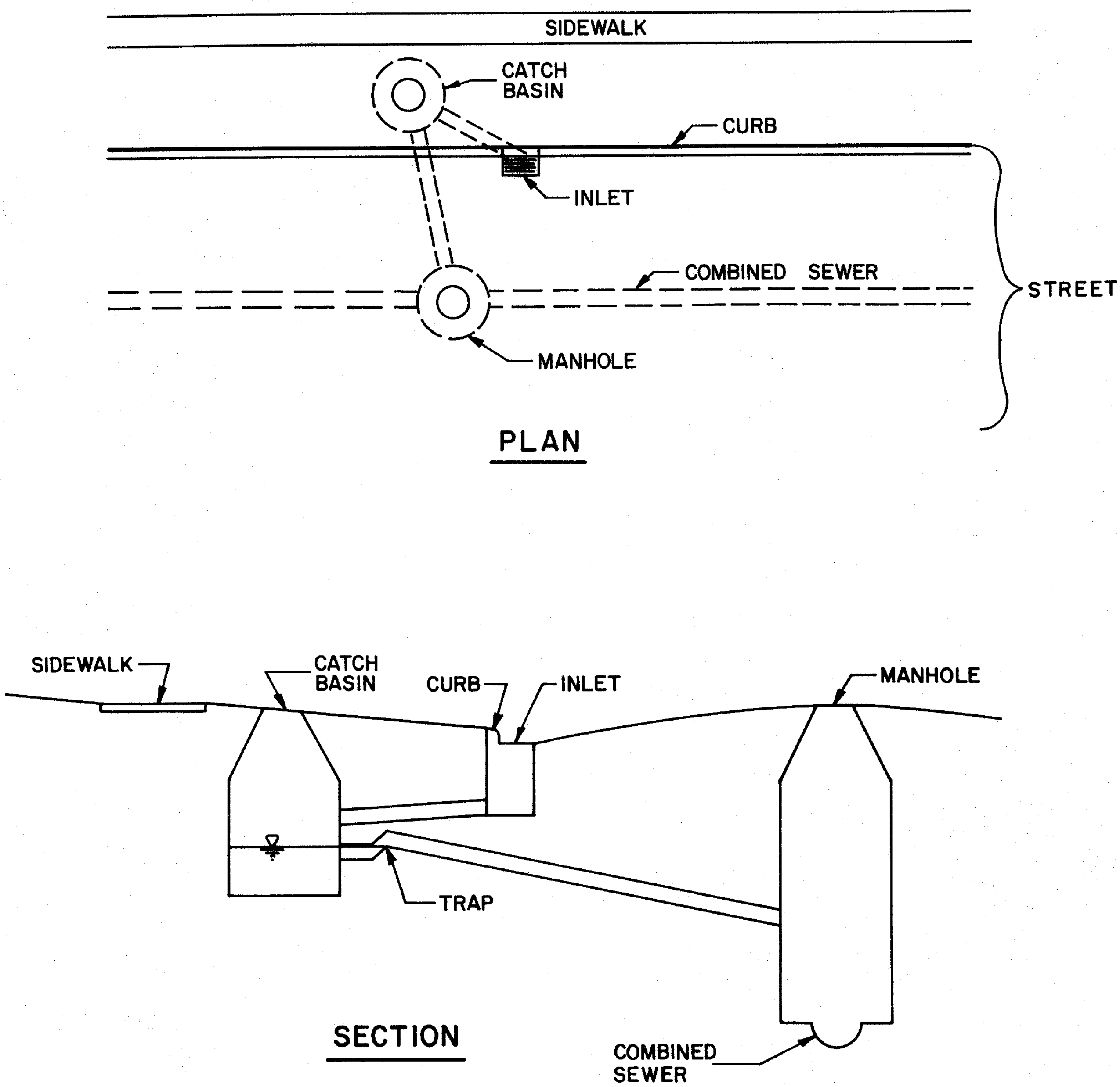


Figure 3-17. Typical configuration of an inlet, catch basin and manhole in the Skokie combined sewer system (Source: Donohue, March, 1984a, p. 3-2).

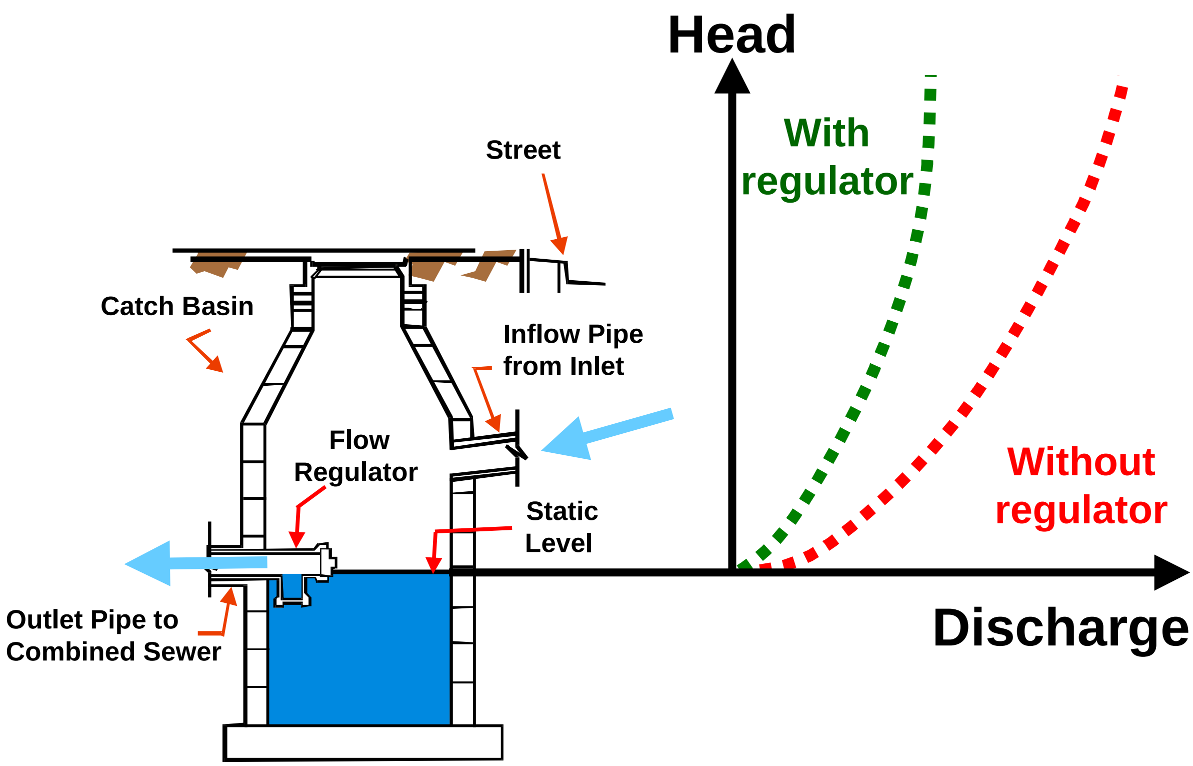


Figure 3-18. A flow regulator installed in a catch basin illustrates the basic function of the regulator.

In Wilmette's CSS, a pair of special catch basins were constructed immediately upstream of berms and fitted with flow regulators. These catch basins were connected to a single new manhole on the adjacent combined sewer. In some cases, as described in the Chapter 9 section titled "Summary of Interviews with Wilmette, IL Officials," shear gate flow regulators were placed at the downstream end of pipes connecting the catch basins to the combined sewer manholes.

In summary, suitable catch basins and manholes already existed in Skokie and the catch basins needed only to be fitted with flow regulators. Existing inlets often had to be moved or new ones installed. In Wilmette, new catch basins, which also served as inlets, had to be constructed as did new manholes on the adjacent combined sewer.

Combined Function of Berms and Flow Regulators.

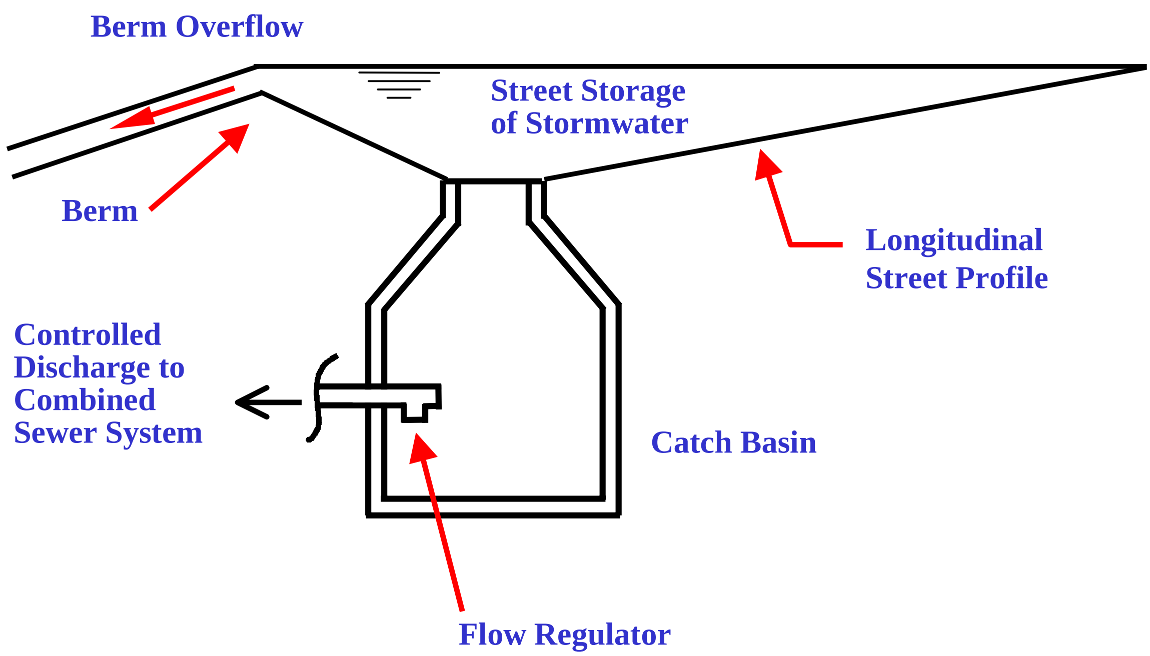
Functioning together, berms and flow regulators become, in what more traditional stormwater management is called, an outlet works. The berm-flow regulator combination, like the outlet works on a traditional stormwater detention basin, is sized and configured to temporarily store stormwater to achieve a desired attenuation of the stormwater runoff hydrograph.

Figure 3-19 shows how a berm on a street and a flow regulator in a catch basin cause temporary ponding of water on the street during and immediately after a runoff event. During and immediately after the event, the peak flow from the catch basin is limited, by the design of the flow regulator and the berm, to what can be conveyed by the receiving combined sewer without surcharging. After, the event, the temporarily stored water drains by gravity through the catch basin.

Figure 3-20 takes the description of the combined function of berms and flow regulators one step further. Shown here is a hypothetical profile, with great vertical exaggeration, along the longitudinal axis of a street. Berms and flow regulators (the flow regulators are not shown) are strategically placed to take advantage of the storage capacity along the length of the street. Low points, which are also storage areas, are used with peak outflow of stormwater to the CSS also being governed by flow regulators.

Recall the earlier brief discussion of a common adverse reaction to constructing berms across streets. This was answered, in part, by noting that stormwater berms have even less impact on vehicles than do the engineered and widely used speed humps.

A similar negative reaction is frequently expressed in response to the suggestion of intentionally storing stormwater on streets. Experiences in Skokie, Wilmette and elsewhere indicate that this initial objection may be offset by offering the following three points for consideration:



Note: Not to scale and great vertical exaggeration

Figure 3-19. Longitudinal profile of a street showing how a berm and flow regulator function as the outlet works of a temporary street storage facility (Source: Adapted from Loucks and Morgan, 1995).

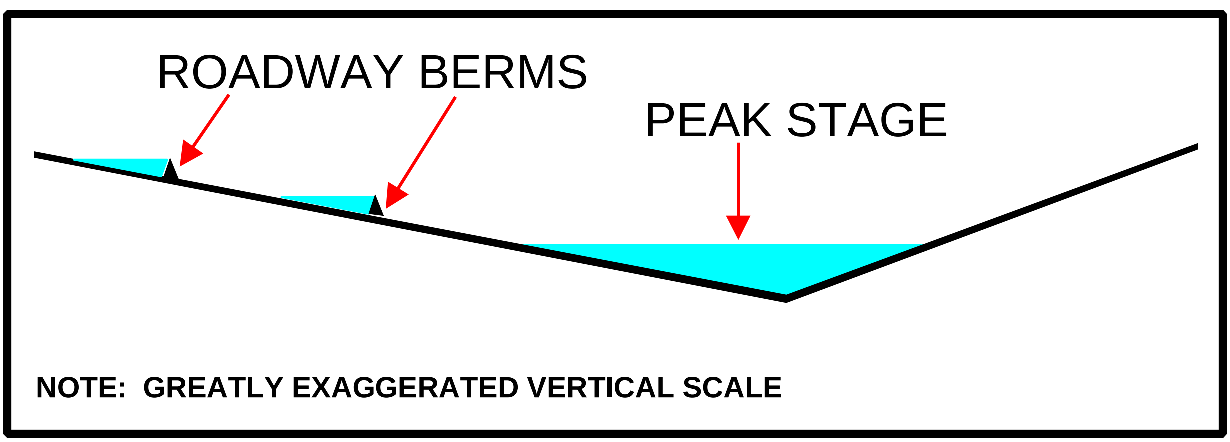


Figure 3-20. Strategic placement of berms and flow regulators along a street facilitates use of the street's capacity to temporarily and in a controlled fashion store stormwater.

- Urban Streets often flood anyway, especially in flat topography typical of CSSs. That flooding is unintentional, uncontrolled and unexpected and can cause damage and excessive disruption of vehicular traffic as indicated by the upper portion of Figure 3-21.

- Stormwater "flooding" in the street storage system is controlled, that is, the peak stage and lateral extent are predetermined by the design of berms and flow regulators. The idea of street temporary controlled storage of stormwater is illustrated in the lower portion of Figure 3-21. The goal is to prevent damage to adjacent properties and not unnecessarily disrupt vehicular traffic.

- Controlled stormwater on streets is much preferred over uncontrolled combined sewage in basements.

Shown in Figure 3-22 are photographs of actual street storage in Skokie and Wilmette. Note that the ponding is shallow, does not prevent vehicular movement, and is contained within the public right-of-way.

Subsurface Storage

Subsurface storage facilities are expensive, but sometimes necessary, components of a street storage system. They are used for temporary storage of stormwater beneath those streets and parking lots where the required surface storage would cause damage.

Subsurface storage is used only where absolutely needed because of the typical high cost per unit volume of storage. Accordingly, street storage systems will typically have very few subsurface storage facilities relative to on-street and other surface facilities. Skokie's 8.6 square mile street storage system, for example, contains only 83 subsurface storage facilities compared to 871 berms and 2,900 flow regulators.

Figure 3-23 illustrates the function of subsurface storage. The facility lies within the public right-of-way and is positioned above the combined sewer. Its outlet is controlled by a flow regulator. Stormwater, not combined sewage, is temporarily stored in the facility.

Actual subsurface storage facilities range from simple to complex configurations depending on the volume of storage required and site constraints. Some facilities are simply oversized lengths of storm sewer while others are large rectangular structures extending the length of a block and the width of the street. An example of the latter is illustrated in Figure 3-24. Shown is the construction of a subsurface storage facility composed of precast, reinforced concrete sections.

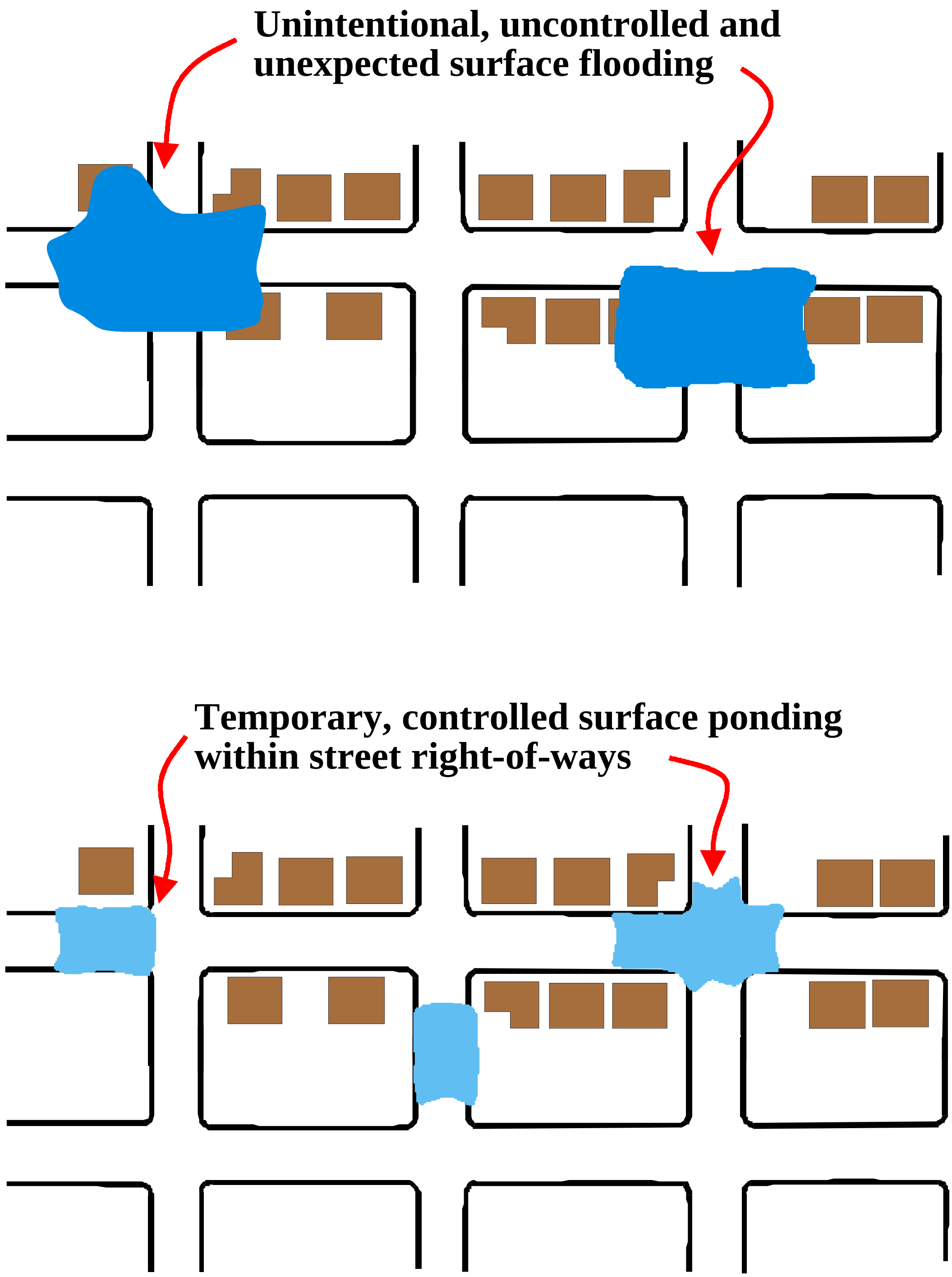


Figure 3-21. The street storage approach uses temporary, controlled ponding of stormwater in contrast with the common unintentional, uncontrolled and unexpected ponding resulting in damage and vehicular interference.

Figure 3-22. Actual street ponding in Skokie (top) and Wilmette (bottom).

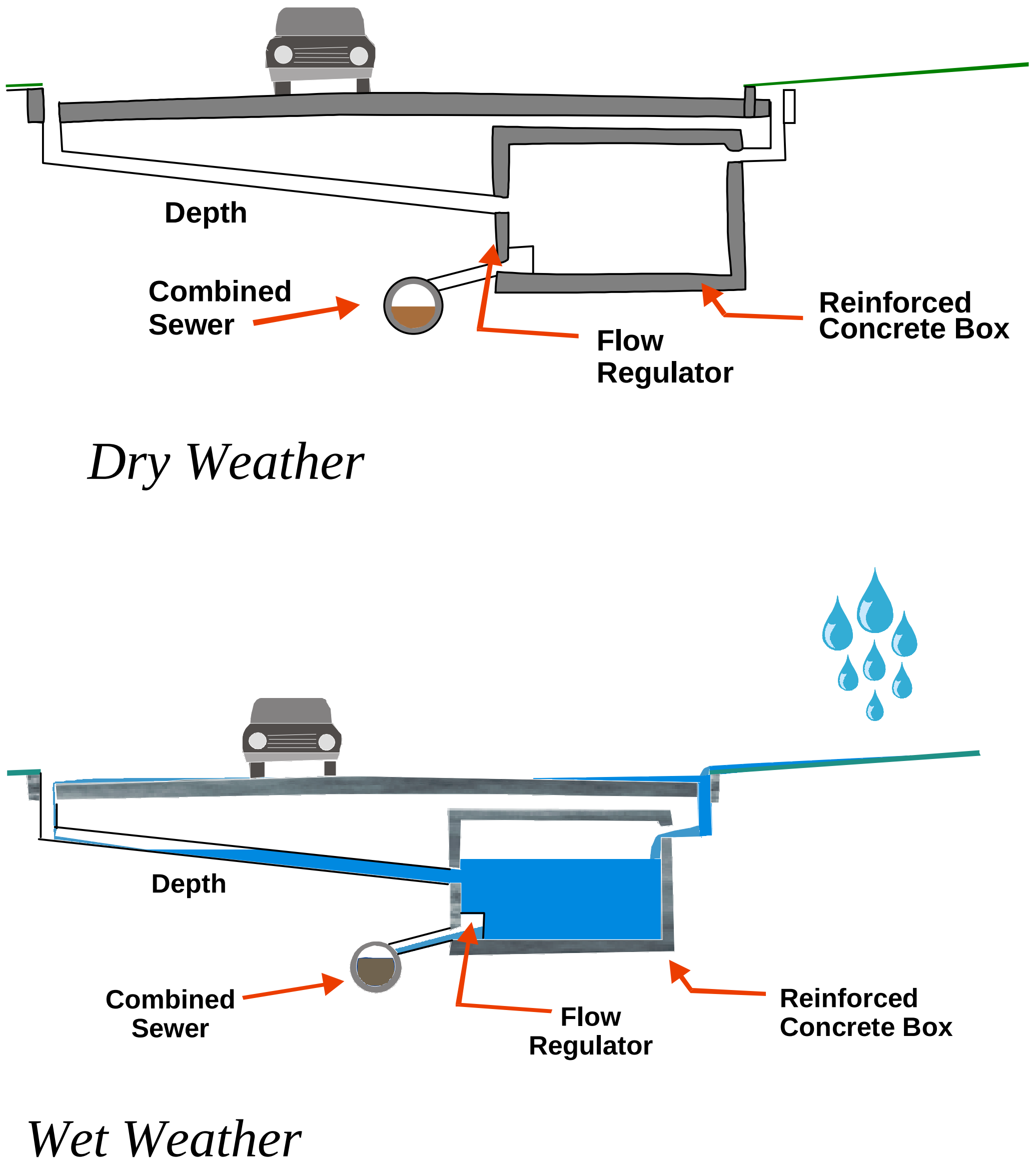


Figure 3-23. Subsurface storage facilities are positioned within the right of way, above the combined sewer and temporarily stored stormwater, not combined sewage.

Figure 3-24. Subsurface storage facilities range from simple oversized lengths of storm sewer to, as shown here, large structures assembled from precast reinforced concrete sections.

Apply Screening Criteria to Determine Likely Applicability of A Street Storage System

Refer to the section in Chapter 10 titled “Criteria for Screening the Applicability of Street Storage.” The screening criteria are based largely on ideas and information presented in this report, that is, the criteria reflects experience with the successful implementation of street storage systems. Included in the previously noted section of Chapter 10 are an explanation of the purpose of the screening criteria, comments about the qualifications of evaluators, reference to the actual criteria which are presented in Appendix B, suggestions for interpreting the information.

Select an Initial Pilot or Implementation Area Within the Combined Sewer System

Need for Phased Implementation

Traditional public works projects, such as streets and highways, wastewater collection and treatment, and water supply treatment and distribution, are often implemented in a phased manner. Budgetary constraints are usually the reason for prioritization and phasing. That is, there is a need to spread capital costs over a period of years so that they match revenues.

Phasing means prioritization. If costs are the principal reason for phasing, then a phased public works project begins with the most cost-effective component. However, other factors can establish priorities including physical constraints, regulatory compliance, and political considerations.

When non-traditional approaches, such as street storage, are an integral part of a public works project, another important reason arises for phasing. That reason is the need to be cautious as the new technology is gradually conceptualized, planned, designed, tested, refined, understood, and accepted. Phased implementation was heavily used in the Skokie street storage project because it is the first large scale application of the street storage system in the U.S.

The key to effective phasing is selection of the first or pilot implementation area. The purpose of this section of the chapter is to offer suggestions, based on the Skokie, Wilmette and other experiences, on factors to consider in selecting the physical area for the first phase of a street storage project and then prioritizing subsequent phases.

Prioritization Factors

Many factors could be weighed in selecting an initial implementation area and prioritizing subsequent areas. Factors to use and their relative weights will depend on a given community’s physical, regulatory, and socio-economic situation. In picking an initial implementation area or the next area in order of decreasing priority, consider selecting an area that:

- Includes a complete drainage system or watershed. The analysis and design process requires, for any point in the system, consideration of all significant conveyance and storage components upstream of that point. The entire 1255 acre HSSD, one of three combined sewer districts in Skokie, was selected as the initial area. It is a CSS watershed that discharges to the interceptor sewer system of the MWRDGC. While selecting a head water portion of this sewer district would have been acceptable, choosing a middle or lower portion of the district would conflict with this factor.

- Best satisfies the screening criteria for street storage. These criteria are introduced in the preceding section of this chapter, elaborated on in Chapter 10, and attached as Appendix B.

- Has a high concentration of basement flooding or other problems. By using this approach, and assuming implementation proceeds through construction, the selected area is likely to be very cost effective. That is, the ratio of problems solved to dollars expended should be higher than if other areas with less concentrated problems are selected.

- Reflects stakeholder input. An advisory committee of stakeholders might be formed to help select the initial implementation area. Stakeholder groups to be represented on the advisory committee might include homeowners, business people, educators, environmentalists, and regulators. Technical and other support should be provided by the community possibly with the assistance of their engineering consultant. In Skokie, the HSSD was selected by the community and then a consulting engineering firm was retained (Donohue, 1982a, p. 11).

- Has characteristics typical of other areas. Skokie, for example, selected portions of four streets covering approximately ten blocks within the HSSD for testing of flow regulators. The referenced pilot study is discussed in detail later in this chapter. One requirement for the testing of flow regulators was that the selected areas have a number of inlets and catch basins per unit area approximating that of the HSSD. In addition, street cross sections and widths in the selected areas were to be representative of the HSSD (Donohue, 1984a, pp. 3-13, 3-14). As further suggested by this Skokie example, use of one or more small pilot study areas within the overall initial implementation area may be prudent.

- Offers cost or other advantages if quick action is taken. As an example of this opportunity factor, one of several candidate CSS drainage areas may be slated for near future street resurfacing. Given that street geometry is critical to street storage, that CSS drainage area may be the logical place to begin implementation of street storage.

Establish Performance Criteria

Need for Performance Criteria: Analysis and Design

Before a CSS can be diagnosed, that is, analyzed to determine the cause of problems, the desired performance must be defined. The desired performance serves as the benchmark against which the severity of CSS problems and the nature of their causes can be measured.

Likewise, the prescription of solutions to a CSS's problems, that is, planning and design, cannot be undertaken until the desired performance of the CSS is defined.

Variation in Performance Criteria

Presented in this section of the chapter are examples of performance criteria used in the Skokie and Wilmette and other street storage systems. While there are some commonalities, the presented performance criteria show significant variations. This is to be expected for the following three reasons:

1. The street storage technology is relatively new and, therefore, rapidly evolving. Something learned in one project, or one phase of a given project, may change the performance criteria for the next project, or next phase of a given project.

2. Special circumstances. For example, a community with many tree-lined streets is likely to include in their performance criteria provisions intended to protect that amenity.

3. Different level of service expectations. Some communities have higher expectations for the level of public services that they receive and are willing to pay for.

Performance criteria presented here are not necessarily recommended for other communities. Rather, they are offered as examples of what some communities have developed to be consistent with their familiarity with the street storage technology, their special circumstances and their level of service expectations. Each community

contemplating use of the street storage system should formulate their own performance criteria, possibly using the criteria presented here as a guideline.

Skokie Performance Criteria

Performance criteria for Skokie's street storage system were first formulated in 1982 as part of the preliminary engineering for the HSSD (Donohue, 1982a, p. 5-1). They were slightly modified as part of a refinement of the HSSD preliminary engineering (Donohue, 1984, pp. 5-1, 5-2), the preliminary engineering for the MSSD (Donohue, 1987b, pp. 6-1, 6-2) and the preliminary engineering for the Emerson and Lake Streets Sewer District (Donohue, 1987a, pp. 5-1, 5-2). These criteria changed relatively little during this five year preliminary engineering period. Therefore, the performance criteria for the Emerson and Lake Streets are presented here as being representative of the Skokie approach.

The explicitly documented Skokie performance criteria may be summarized as follows:

1. The street storage system should be designed for the 10-year recurrence interval storm.

2. Reduce surcharging of sewers to prevent sewage backup caused by overloading of the municipal sewer system. The preliminary design of the alternatives is developed with the concept of defining maximum stormwater runoff rate into the sewers while preventing damaging sewer surcharging.

3. Make utilization of available street ponding capacity without causing flood damage to adjacent private development. Berms are to be used to detain stormwater on upland streets.

4. Minimize ponding on state and county highways. Stormwater ponding is discouraged on such streets. In locations where street storage on nearby streets could increase ponding depth on or near state and county highways, roadway berms are to be use to prevent ponding on the state or county highways. Storage facilities or relief sewers are to be used in no-pond areas to accommodate stormwater in excess of sewer capacity.

5. Establish maximum permissible flood stage for each street on a block-by-block basis. This stage, referred to as the "critical" elevation, is the highest stage which can be tolerated on the block without incurring flood damage such as first floor flooding and the flow of surface water through windows into basements or into below grade garages. In most cases the sidewalk elevation at the lowest point in the block is the critical elevation.

6. Confine temporarily stored stormwater within the right-of-way during the 10-year recurrence interval design storm. Right-of-way typically extends from the back of the sidewalk on one side of the street to the back of the

sidewalk on the other side. Limit the maximum depth of ponding for the 10-year storm to the lesser of six inches at the street centerline or nine inches at the gutter invert.

7. TARP Phase I provides a discharge point that will carry the stormwater runoff from a 10-year recurrence interval storm.

8. A gravity operated stormwater system is preferred to a pumped system. Minimal use of electrical and mechanical controls and equipment is desirable. A simple gravity operated system reduces the likelihood of failure and minimizes future operation and maintenance costs.

9. Storage of excess runoff should be accomplished first in off-street areas, second on streets, and last in underground storage facilities. Park and private property may also be considered assuming proper arrangements can be made.

10. Downspouts from one and two family residences are assumed to be disconnected from the CSS and to discharge to the land surface or storm sewer system in all street storage areas and in all areas without street storage but having storm sewers and/or stormwater storage facilities. Industrial, commercial and multi-family buildings and any buildings with internal drainage systems are excluded from this assumption.

Wilmette Performance Criteria

The explicitly documented performance criteria for Wilmette's street storage system may be summarized as follows:

1. "Alleviate basement flooding for the 10-year frequency storm event" (Rust, November 1993, p. 1).

2. "Reduce private property flooding (outside of the Village right-of-way) for the 10-year frequency storm event" (Rust, 1993, p. 1).

3. "Limit inconvenience to residents in accessing their property during major rainfall events" (SEC Donohue, December 1992, p. 7).
4. Confine street storage to public right-of-way (SEC Donohue, June 1992, p. 6).

5. Limit ponding depths to a maximum of six inches on the crown of a street and a maximum 12 inches above the gutter invert. Allow no ponding on sidewalks (SEC Donohue, June 1992, p. 7).

6. Exclude designated streets or street segments from ponding. These

streets were selected based on high traffic volume and/or proximity to schools, places of business, and access to or from elderly housing or fire and police stations (SEC Donohue, June 1992, pp. 7-8).

7. Generally consider berms only on streets with flat longitudinal grades—0.5% or less (SEC Donohue, June 1992, p. 16).

8. "Limit inconvenience to the community during the construction process" (SEC Donohue, December, 1992, p. 7).

9. "Limit increases in hydraulic loading on the North Shore Channel" (SEC Donohue, December 1992, p. 7).

10. "Limit increases in pollutant loading on the North Shore Channel" (SEC Donohue, December 1992, p. 7).

11. Limit peak flow discharged to TARP to the negotiated rate for the 10-year design rainfall events (Morgan, 1999).

Although not documented in the available Wilmette reports (SEC Donohue, June 1992; SEC Donohue, December 1992; and Rust, November 1993) other important performance criteria, in addition to the preceding list, were apparently applied in Wilmette. These seem to include the previously presented Skokie performance criteria 8, 9 and 10.

Analyze Existing System Using Monitoring

The suggested systematic analysis and design process for a street storage system should include, as shown in Figure 3-5, monitoring data. That data may already exist from previous studies, may be collected as part of a special monitoring effort, or be a combination of the two. Regardless of data origin, the data should be used in parallel with the previous described computer modeling. Ideally, iteration should occur between modeling and monitoring as suggested by the dashed two-way arrow in Figure 3-5. For example, monitoring data should be used to calibrate hydrologic-hydraulic models. Initial modeling results should be used to identify gaps in the monitoring program. See Walesh (1989, Chapter 10) for a detailed discussion of the interplay between modeling and monitoring. Both Skokie and Wilmette used monitoring during the analysis and preliminary engineering process. Their efforts are described in the following sections.

Skokie Monitoring

This summary of the initial monitoring program is taken from Walesh and Schoeffmann (1984). The monitoring program was conducted in 1983 to:

- Better define the behavior of the existing CSS.

- Provide baseline information to evaluate the performance of the street storage system, which would eventually be implemented.

- Provide data for refinement of the ongoing computer modeling effort.

An overriding consideration was selection of equipment, training of Skokie personnel, and installation of equipment in such a fashion that it could be moved to other sewer districts, after one or more years of service in the HSSD.

A 41 unit monitoring system was installed. It consisted of three rainfall monitoring stations; nine sewer flow monitoring stations with bottle racks installed at all nine monitoring stations and continuous monitors installed in six of the stations; 20 street ponding monitoring stations composed of 15 stations equipped with bottle racks and five with specially designed recording devices; and 10 footing drain flow monitoring stations, three of which were located in the HSSD and seven in adjacent sewer districts.

Installation, startup and calibration of equipment was carried out from January through March, 1983. Training of the Village staff, which occurred in the February through April, 1983 period, included chart changing, battery replacement, calibration, parts replacement and recording procedures. The monitoring system was operated as a joint effort between Skokie and Donohue & Associates, its consulting engineering firm, until the end of October, 1983. Additional, selective monitoring was conducted in 1984 within and outside of the HSSD.

The monitoring program revealed that precipitation exhibits significant spatial variation across the HSSD with half of 16 monitored major storms exhibiting such a variation. Dry weather flow values were found to be similar to those assumed in preliminary analyses (which relied solely on computer modeling as described in subsequent sections of this chapter) but exhibited significant spatial variation which was subsequently included in the refined analyses. Foundation drain flows were determined to be about one-third of the values assumed in the preliminary analysis. Accordingly, foundation drain contributions were reduced from about 2,900 gallons per day per house to about 1000 gallons per day per house.

Wilmette Monitoring

Flow monitoring was performed primarily to obtain data for calibration of SWMM. SEC Donohue (December 1992, p. 8) describes the monitoring program as follows:

> *Flow meters were installed at five locations in the... sewer system and operated from July 10, 1991 through September 9, 1991. Rainfall over the flow metering period was measured using a continuous recording rain gauge. Total*

> *rainfall for the flow monitoring period was 5.3 inches, the largest storm event was 1.6 inches, and a number of smaller events were also recorded.*

A second purpose of the Wilmette monitoring program focused on system behavior along the west boundary of the CSS. There was concern that MWRDGC interceptors along this boundary might surcharge and impact the tributary portion of the CSS. No surcharging occurred during the monitoring period. However, this observation was qualified by the fact that no severe rainfalls occurred during the monitoring. This is an example of using monitoring to diagnose system behavior.

Analyze Existing System and Perform Preliminary Design Using Computer Models

A Complex System: Need for Computer Modeling

A typical combined sewer system is complex with its many and varied sanitary, stormwater and other inflows and its tendency to surcharge. Overlay a rectilinear system of street storage and conveyance components and the complexity increases.

Because of the complexity of the existing and possibly modified CSS, computer modeling has proven to be a necessity. Hydrologic-hydraulic computer modeling was heavily used in the Skokie and Wilmette projects. Computer modeling has been used for both analysis and preliminary design, that is, diagnosis of problems and development and prescription of solutions.

The models used and the manner in which they were used has naturally evolved, given the approximately 15 year period during which analysis and design occurred in the Skokie and Wilmette projects. Much was learned during this period as indicated by the subsequent sections. Presented here are summaries of computer modeling approaches used at various stages of the Skokie and Wilmette projects. Hopefully, the ideas and information presented will be helpful to CSS communities contemplating the use of computer modeling and the street storage approach.

Assuming a discrete event, contrasted with a continuous computer model (Walesh, 1989, pp. 321-324) is to be used, a design storm or design storms must be selected as part of the modeling. This typically includes decisions on recurrence interval, duration, volume, and hyetograph shape. Sensitivity analyses should be part of the process of formulating the design storm or storms. Detailed discussion of design storms is beyond the scope of this manual.

For in-depth discussion of design storms, see Walesh (1989, pp. 98-99, 112-113, 129, 304) and ASCE-WEF (1992, pp. 69-78, 226). An example of a sensitivity analyses used to determine the critical duration for a design storm is provided by Walesh (1989, pp. 361-363).

Analysis and Preliminary Design for the HSSD in Skokie

A three-phased approach was used in the modeling and the analysis and preliminary design of the HSSD. The following description of the approach is taken from Walesh and Schoeffmann (1984).

Phase I was a simple static condition analysis, done without computer modeling, to determine the effect of North Shore Channel flood stages on flooding in the HSSD. Phase II was the steady-state hydraulic analysis of the sewer system, using a computer modeling, to determine the capacity available for stormwater runoff. Phase III was the determination of the location and extent of street flooding which would occur for various recurrence interval storms and the location and size of supplemental surface storage and relief sewers. This, the last phase was heavily dependent on computer modeling of the dynamic hydrologic-hydraulic system.

Phase I - Analysis of Static Conditions

This analysis determined if flood levels on the North Shore Channel, the ultimate receiving water for the HSSD CSS, would cause basement flooding solely as a result of backwater. The analysis was motivated by the observation that surface and subsurface storage of stormwater in the HSSD could not resolve basement flooding that resulted solely from North Shore Channel backwater effects. The analysis was conducted to determine if there were portions of the HSSD in which flood control could not be achieved by a street storage system within the HSSD.

The procedure used in this analysis is illustrated in Figure 3-25. North Shore Channel flood levels were obtained from the Corps of Engineers (Stadler, 1982) and the MWRDGC (MSDGC, 1981). Elevations of inverts and crowns of sewers in the HSSD, which were determined from sewer atlas maps and field surveys, were used to estimate the elevations of basement floors. Basement floor elevations were then compared to the flood levels.

The analysis concluded that there are no significant areas in which basement flooding would result solely from backwater of the North Shore Channel. Therefore, flood control within the HSSD might be achieved by an in-HSSD street storage system.

Phase II - Analysis of Sewer Capacity

The portion of the CSS capacity available for carrying stormwater runoff is a function of: the total hydraulic capacity of the system as determined by pipe size, slope, and material; the quantity of sanitary flow, infiltration, and foundation drainage entering the system; and the level to which the sewer can surcharge without causing basement flooding or other damage. Capacity is also affected by the backwater effect of downstream sewers. The maximum allowable surcharge level was set at the crown of the sewers to avoid backup of combined sewage into basements.

For the sewer capacity analysis, flows representing foundation, sanitary and infiltration components were established based on a concurrent monitoring program. Roof drains were assumed to discharge to the land surface and no longer be directly connected to the CSS as a result of the Village's largely completed downspout disconnection program. The following flow components were used:

- Foundation flow: 5,000 gpd/acre or 0.0075 cfs per acre based primarily on monitoring.

- Sanitary and infiltration flow in residential areas: a total of 3,000 gpd/acre or 0.0047 cfs/acre for the western 90 percent of the HSSD and 6,000 gpd/acre or 0.0093 cfs/acre were used for the remainder of the HSSD based on monitoring.

- Sanitary and infiltration flow in industrial areas comprising the eastern approximately 10 percent of the HSSD: 11,000 gpd/acre or 0.017 cfs/acre based on monitoring.

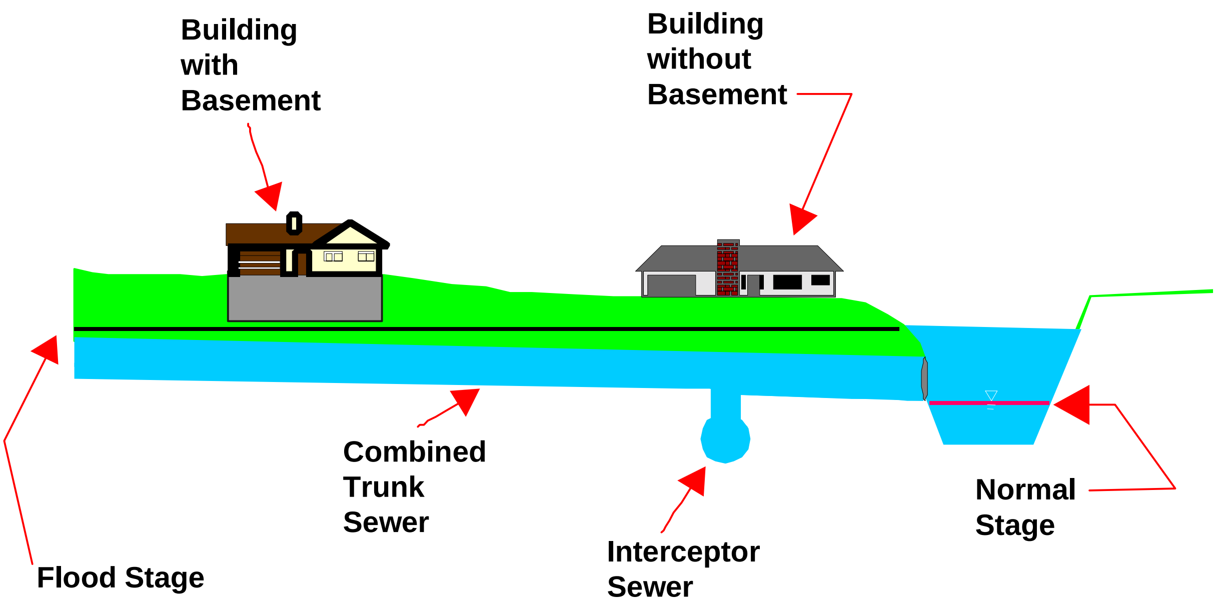


Figure 3-25. Phase I, a simple static condition analysis, was used to determine if high stages on the North Shore Channel caused basement flooding in the HSSD.

The intent of the analysis was to determine the maximum rate at which stormwater runoff could be released into the CSS without exceeding the established surcharge level. The analysis is analogous to establishing the maximum allowable release rate from a conventional stormwater storage facility based on the capacity of downstream conveyance works.

The sewer capacity analysis was carried out using the computer program System Analysis Model (SAM), which permitted simulation of the entire HSSD and provided the computational means of accounting for system surcharges and hydraulic grade lines for each trunk and branch sewer (CH2M Hill, 1980). Refer to Figure 3-26 for a overview of the computer modeling procedure. The dry weather module of SAM was used to develop and input flows to the sewer system and the transport module was used to combine and route the flows through the sewer system. The HSSD was represented in the model as 101 subbasins, having an average area of 12 acres, and 161 sewer segments, having an average length of 300 feet.

Foundation, sanitary and infiltration flows were input to the CSS. Increasing stormwater runoff rates were then progressively added to the sewer system on a subbasin by subbasin basis until the hydraulic grade line in the sewer met the established allowable surcharge level.

The allowable runoff rates represent design conditions, that is, the maximum rate at which stormwater can be released into the CSS without causing sewer surcharge and basement flooding. For this no-surcharge condition, the maximum allowable stormwater runoff rate ranged from 0.1 to 0.2 cfs per acre.

The resulting allowable stormwater runoff rates are extremely low. These unit area rates are equivalent to the runoff from an impervious surface that would be generated by a continuous rainfall intensity of only 0.1 inches per hour. Stated differently, the computer modeling diagnosis revealed that the HSSD combined sewers had very little capacity available for conveying stormwater runoff when allowance was made for sanitary sewage, foundation flow and infiltration.

Phase III - Preliminary Design of Street Storage

This analysis determined the street ponding which would occur as a result of regulating the rate at which stormwater runoff could enter the CSS. More specifically, this analysis determined the location, depth, lateral extent, and duration of street ponding subject to the allowable stormwater release rate and other constraints as described below.

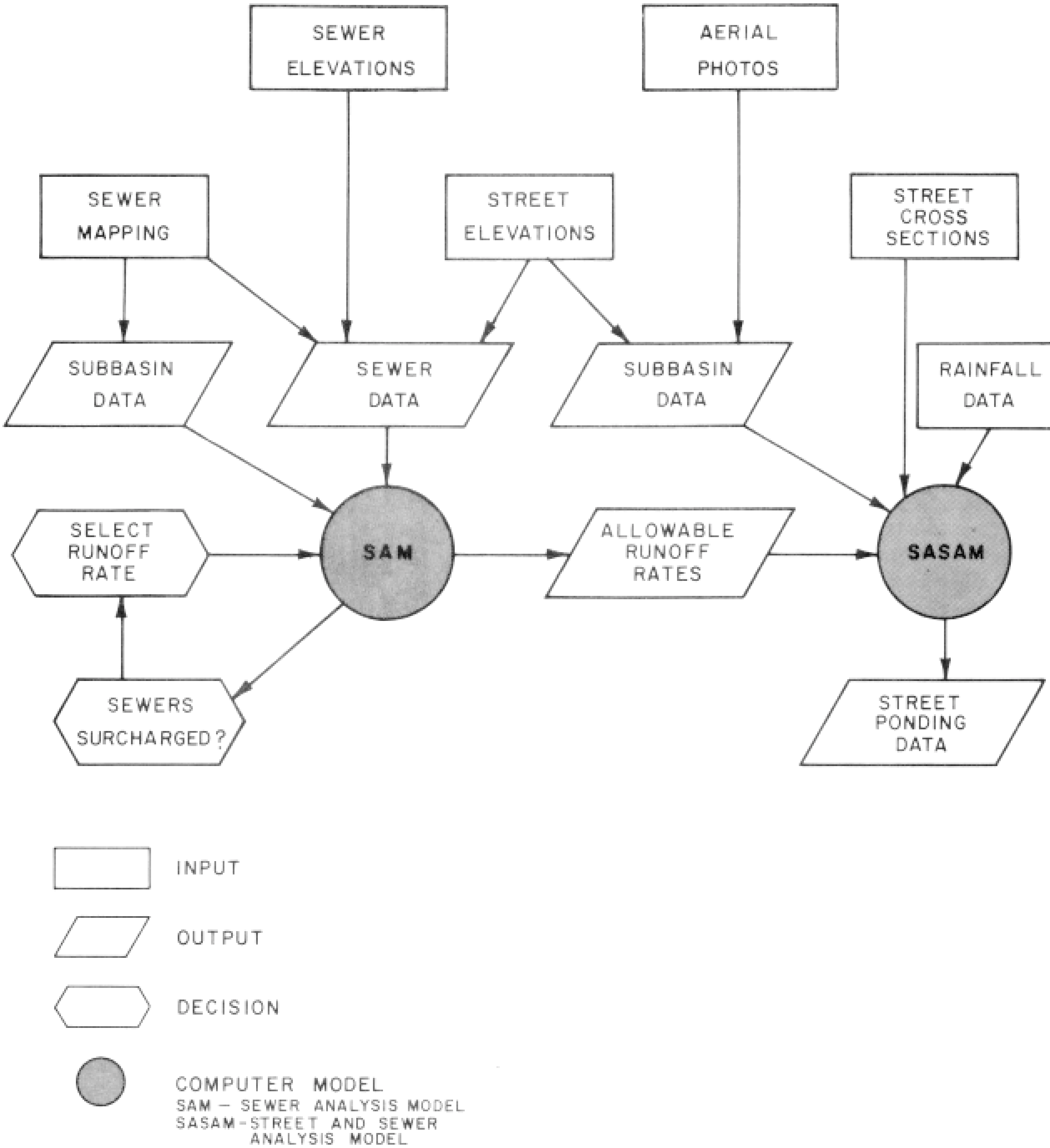


Figure 3-26. Computer model used for analysis and preliminary design in the Skokie HSSD (Source: Donohue, 1982a, p. 45).

A computer program, Street and Sewer Analysis Model (SASAM) was used for the analysis. Refer again to Figure 3-26. Note the relationship between SASAM and SAM. SASAM accepted historic or design rainfall hyetographs and computed runoff hydrographs as a function of subbasin area, time of concentration, and type of land cover using the British Road Research Laboratory Method (Stall, 1972). Flow in streets and on adjacent parkways was routed using the Manning equation plus conservation of mass to account for the conveyance capability of any given street section. Stormwater which ponded on street surfaces and adjacent parkways and lawn was accounted for by a reservoir routing procedure. Release of flow from the street surface to the sewer system was set at the maximum allowable release rates which could be handled by the sewer system as determined by Phase II. Examples of stage hydrographs produced by SASAM are presented in Figure 3-27.

The HSSD was partitioned into 278 subbasins having an average size of 2.4 acres for the Phase III analysis. Drainage area, percent directly connected impervious area, and time of concentration were determined for each subbasin. The street system was represented on a block-by-block basis requiring the use of 278 street segments. Representative street cross-sections, some of which are shown in Figure 3-15, were surveyed. Cross-sections extended from the street face of buildings on one side of the street to the street face of buildings on the opposite side and varied significantly.

The first quartile storm distribution developed on the basis of historic rainfall data in the Chicago area was used in the analysis (Illinois State Water Survey, 1976). Sensitivity analyses using storm durations ranging from 30 minutes to 12 hours indicated that a six hour duration was most critical.

The lowest sidewalk elevation in each block was selected as the critical elevation for the block. The critical elevation is the maximum allowable ponding elevation under design storm conditions.

The modeling process moved on a block-by-block basis in the downstream direction. Excess water from each street was transferred to one or more adjacent downstream streets. In this manner, ponding was maximized for each block. Use of street surface berms was assumed for achieving stage control. Subsurface storage tanks were strategically placed to store excess stormwater from groups of streets having insufficient ponding capacity.

Results

Largely as a result of the preceding three phased analysis and preliminary design process, the engineer recommended moving ahead with a street storage system throughout the HSSD. Skokie accepted the recommendation and implementation of street storage approach eventually encompassed the entire 8.6 square mile community.

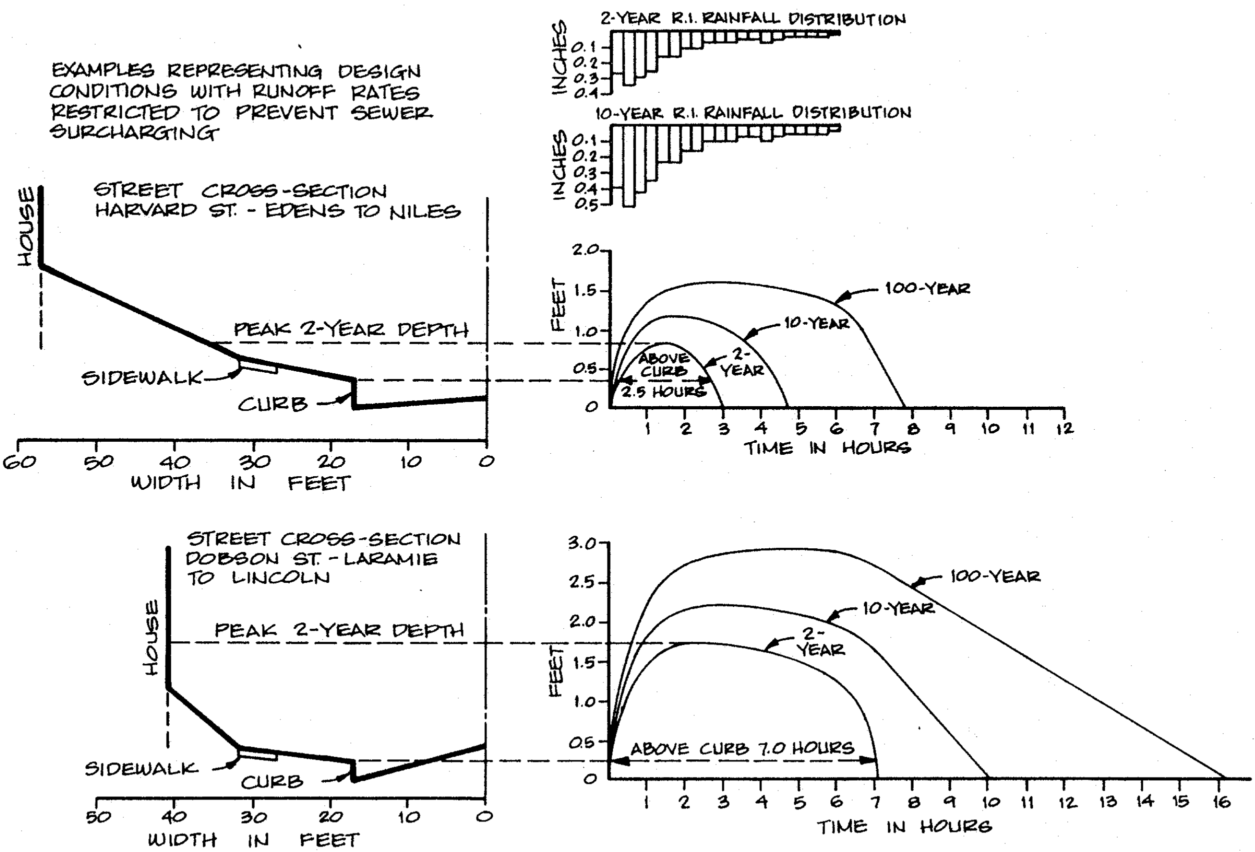


Figure 3-27. Depth and duration of street ponding as a function of recurrence interval (Source: Walesh and Shoeffmann, 1984).